US007733090B2

(12) **United States Patent**
Aoki

(10) **Patent No.: US 7,733,090 B2**
(45) **Date of Patent: Jun. 8, 2010**

(54) MAGNETIC FIELD GENERATOR

(75) Inventor: **Masaaki Aoki**, Takatsuki (JP)

(73) Assignee: **Hitachi Metals, Ltd.**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 543 days.

(21) Appl. No.: **11/631,259**

(22) PCT Filed: **Jun. 28, 2005**

(86) PCT No.: **PCT/JP2005/011843**

§ 371 (c)(1), (2), (4) Date: **Dec. 29, 2006**

(87) PCT Pub. No.: **WO2006/003892**

PCT Pub. Date: **Dec. 1, 2006**

(65) **Prior Publication Data**

US 2008/0303522 A1 Dec. 11, 2008

(30) **Foreign Application Priority Data**

Jul. 1, 2004 (JP) 2004-195878

(51) **Int. Cl.**
G01V 3/00 (2006.01)

(52) **U.S. Cl.** **324/319**

(58) **Field of Classification Search** 324/300–322; 335/296–306

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,660,013 A * 4/1987 Laskaris et al. 335/299
4,672,346 A * 6/1987 Miyamoto et al. 335/296
4,848,103 A * 7/1989 Pelc et al. 62/51.1
4,998,976 A 3/1991 Rapoport
5,063,934 A 11/1991 Rapoport et al.
5,320,103 A 6/1994 Rapoport et al.
5,462,054 A * 10/1995 Rapoport et al. 335/296
5,652,517 A 7/1997 Maki et al.

(Continued)

FOREIGN PATENT DOCUMENTS

CN 1272774 A 11/2000

(Continued)

OTHER PUBLICATIONS

Office Action to the corresponding Chinese Application No. 200580022400.1 w/English translation.

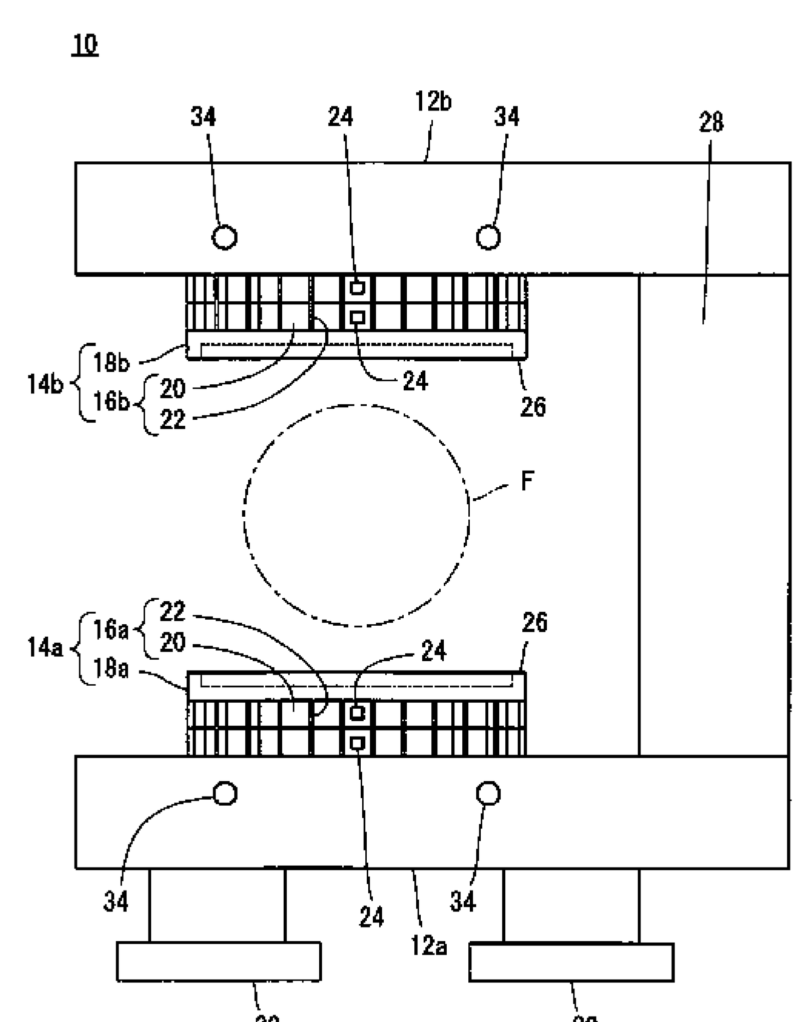
(Continued)

Primary Examiner—Brij B Shrivastav
Assistant Examiner—Dixomara Vargas
(74) *Attorney, Agent, or Firm*—Kratz, Quintos & Hanson, LLP

(57) **ABSTRACT**

There is provided a magnetic field generator which is capable of generating a uniform magnetic field of a desired intensity easily and stably without increasing running cost. The magnetic field generator includes a pair of plate yokes. The plate yokes have opposed surfaces provided with magnetic pole respectively. The magnetic pole includes a permanent magnet group whereas the magnetic pole includes a permanent magnet group. Each of the permanent magnet groups is formed substantially in a disc like shape, as an integral body made of a plurality of permanent magnets and a plurality of heat conducting members. Tubular heaters, buried in the plate yokes, generate heat, which is conducted via the plate yokes to each permanent magnet and each heat conducting member which constitute the permanent magnet groups.

17 Claims, 29 Drawing Sheets



U.S. PATENT DOCUMENTS

6,297,634	B1 *	10/2001	Aoki	324/315
6,332,324	B1 *	12/2001	Saho et al.	62/51.1
6,844,801	B2 *	1/2005	Huang et al.	335/296
6,853,855	B2 *	2/2005	Ideler	600/410
7,084,633	B2	8/2006	Aoki et al.	
7,140,420	B2 *	11/2006	Arik et al.	165/80.2
7,323,135	B2 *	1/2008	Choi et al.	266/90
2002/0171526	A1	11/2002	Laskaris et al.	336/110
2003/0006771	A1	1/2003	Goto et al.	
2005/0092395	A1	5/2005	Aoki et al.	148/102

FOREIGN PATENT DOCUMENTS

EP	1 004 270	A1		5/2000
EP	1 102 077	A2		5/2001
JP	63-43649			2/1988
JP	63-278310			11/1988
JP	02-016702			1/1990
JP	2-23010			5/1990
JP	2-276211			11/1990
JP	03210235	A	*	9/1991
JP	05-212012			8/1993
JP	5-212012			8/1993
JP	05337098	A	*	12/1993
JP	8-266506			10/1996
JP	2001-70280			3/2001
JP	2003-24296			1/2003
JP	2003-305021			10/2003
JP	2004-41715			2/2004
JP	2005065752	A	*	3/2005
WO	WO99/65392	A1		12/1999

OTHER PUBLICATIONS

Supplementary European Search Report dated Aug. 24, 2009 for corresponding EPC Patent Application No. 05765248.9.

* cited by examiner

F I G. 1

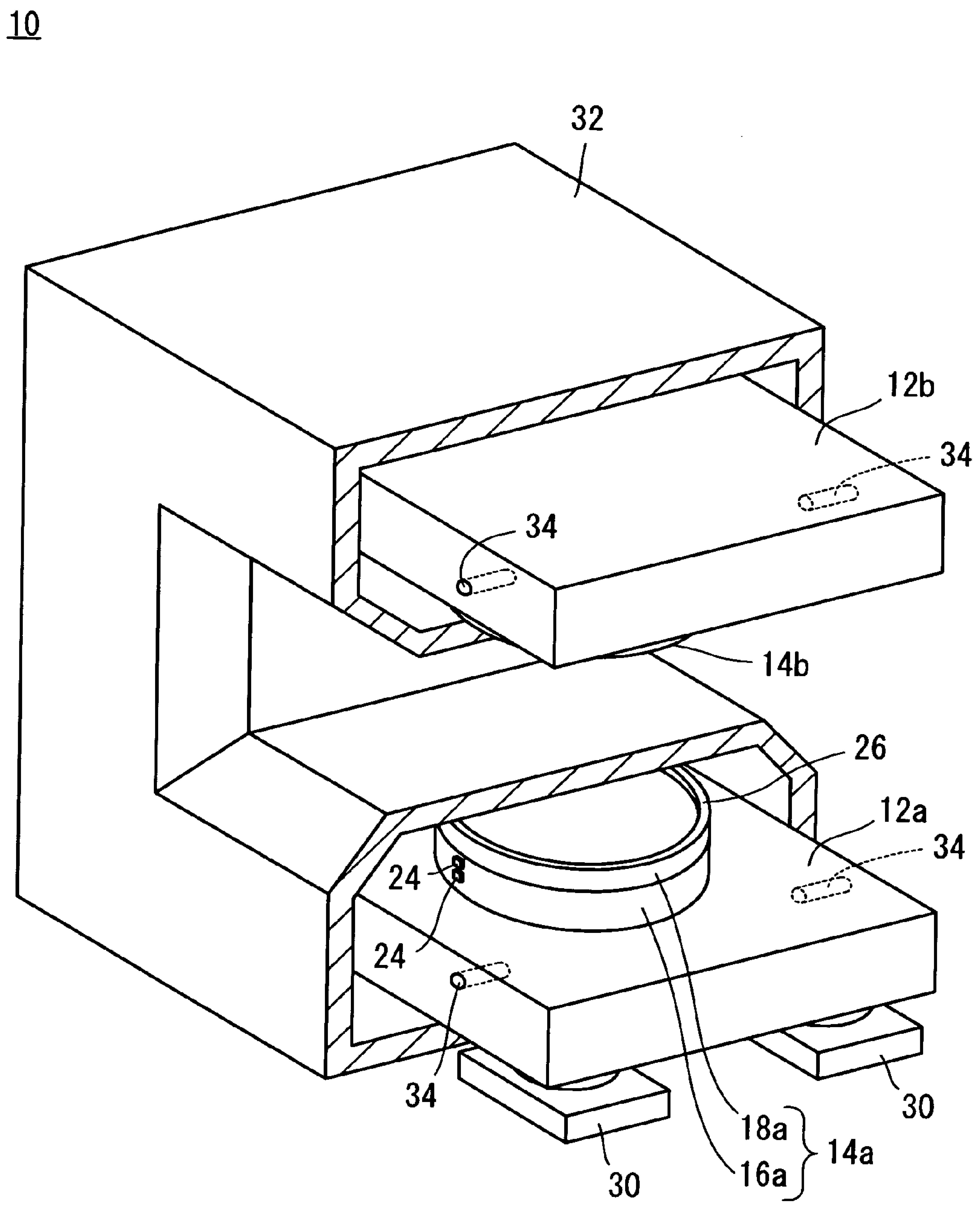


FIG. 2

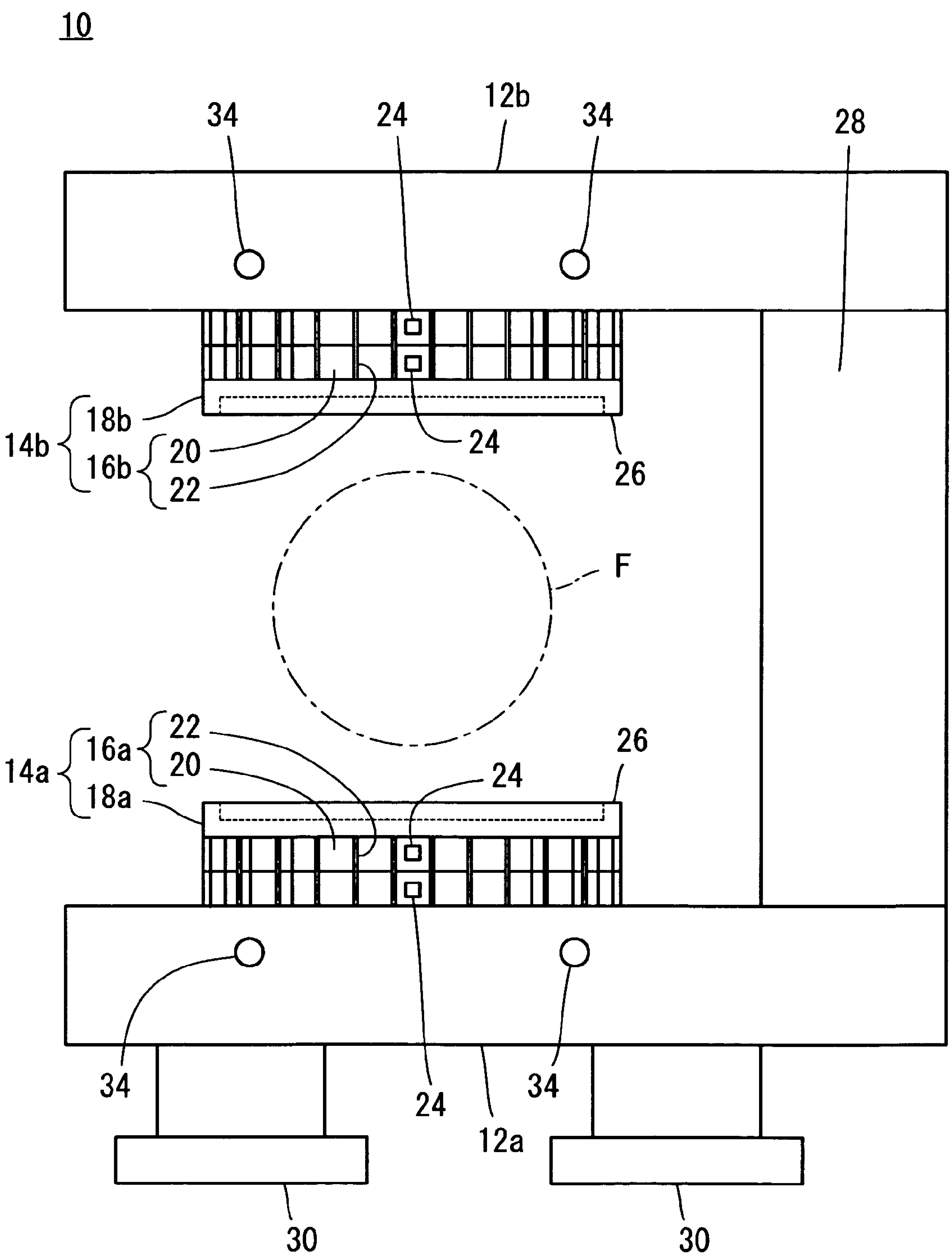
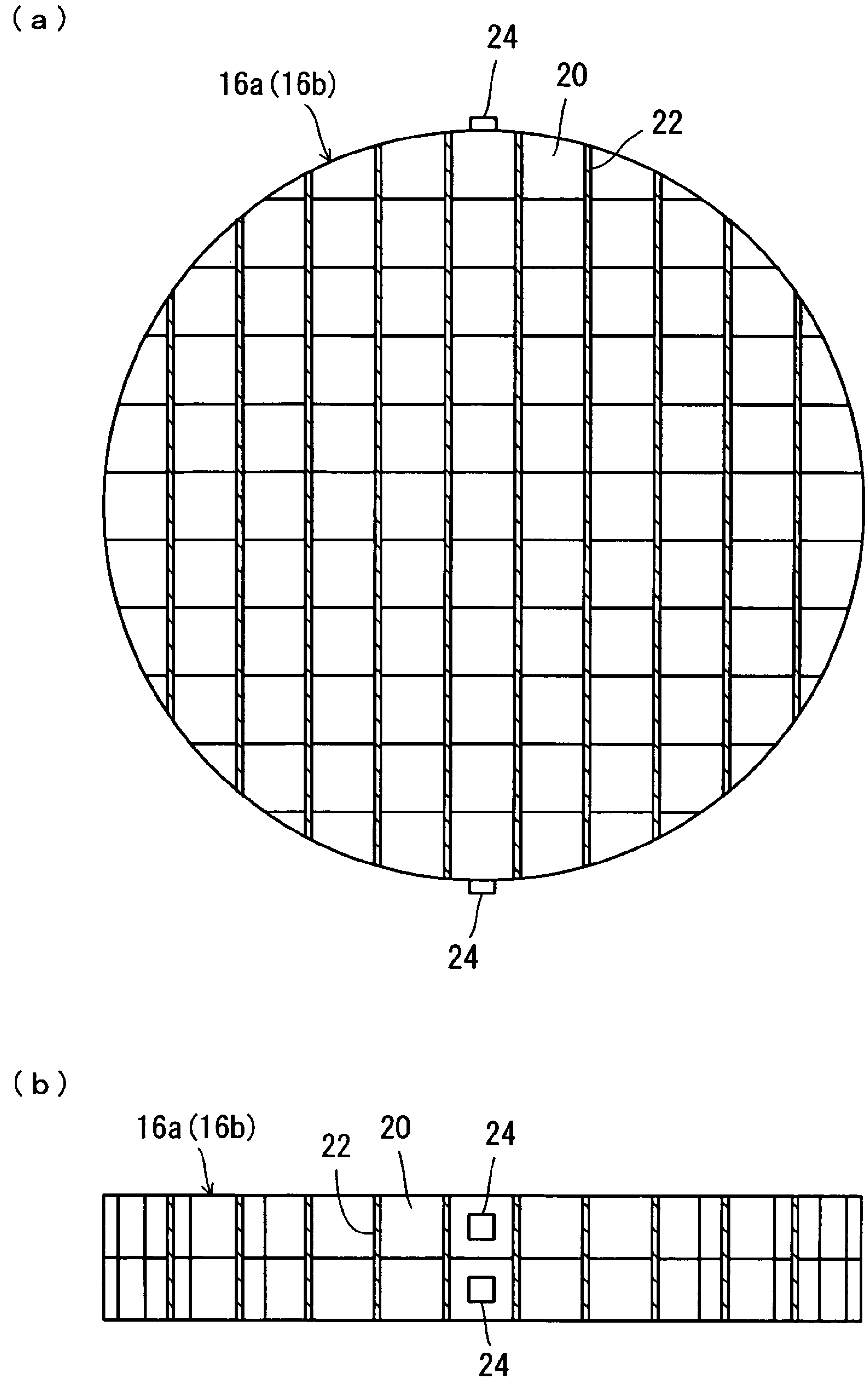
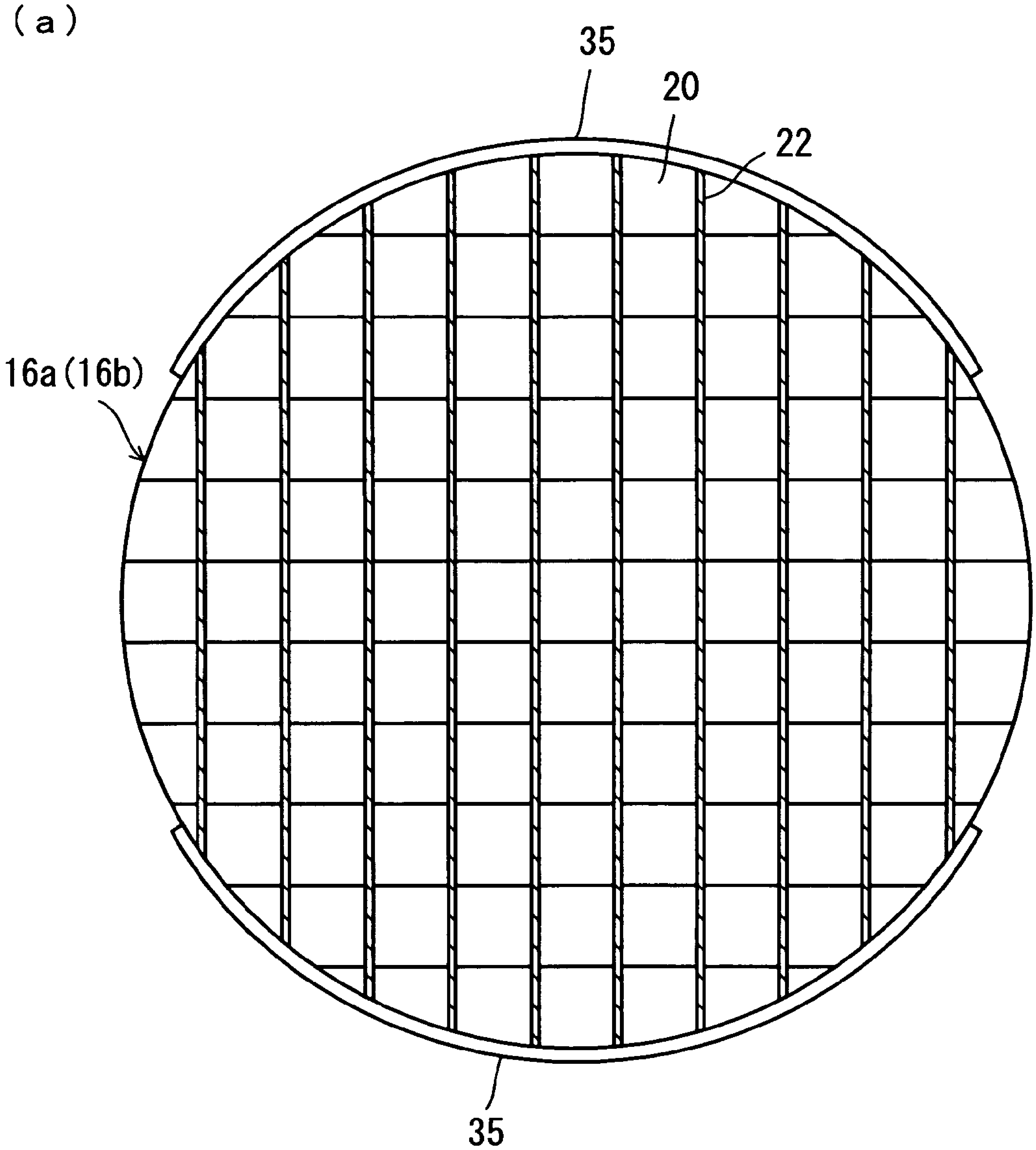

10
34
24
12b
34
28
18b
14b
16b
20
22
24
26
F
22
16a
20
14a
18a
26
24
34
24
12a
34
30
30

FIG. 3

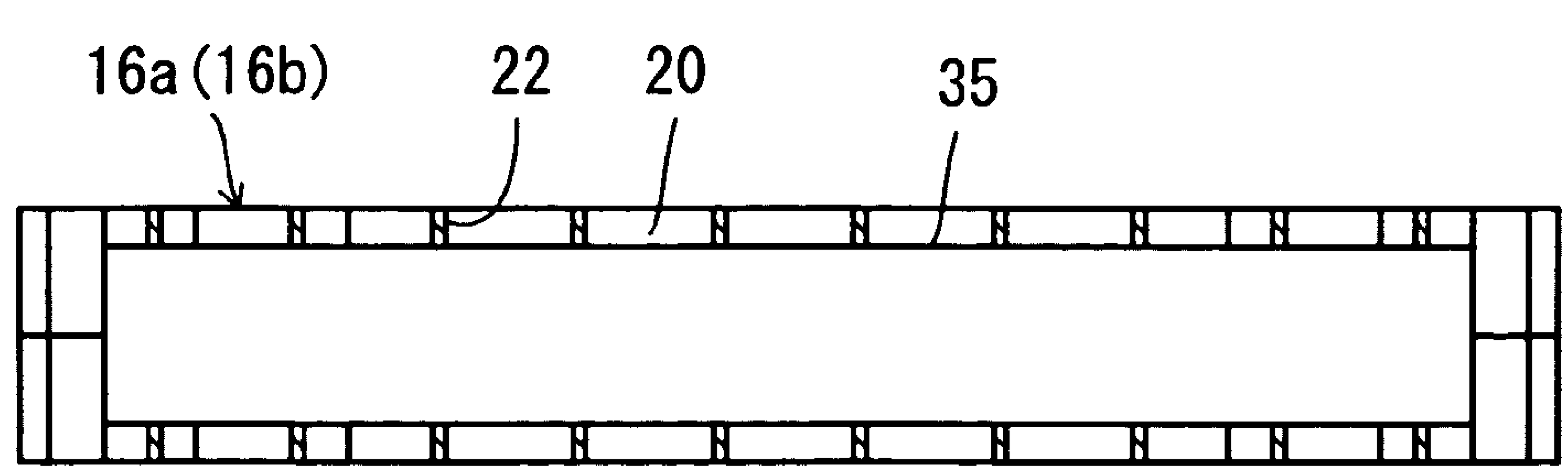


F I G. 4

(a)



(b)



F I G. 5

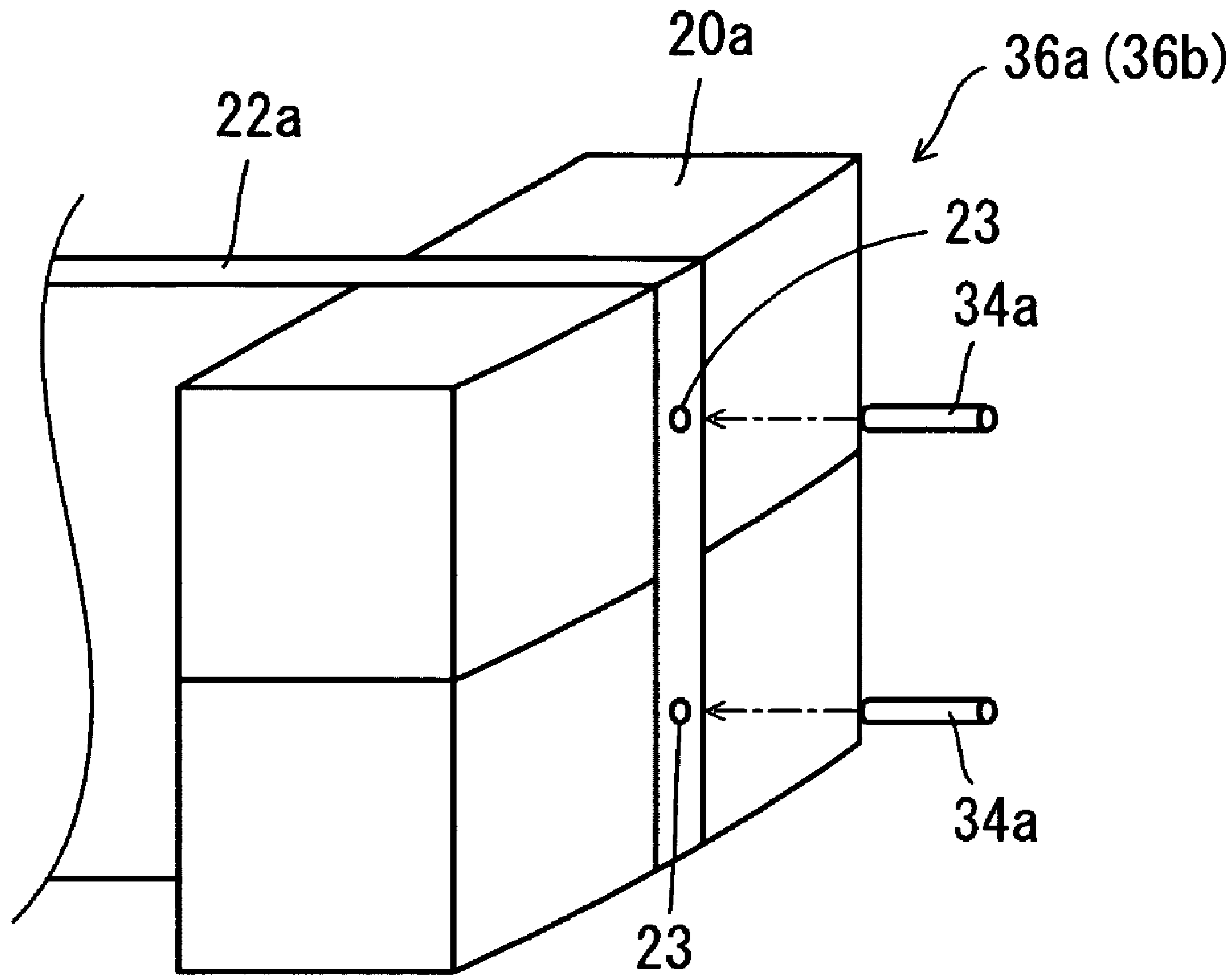
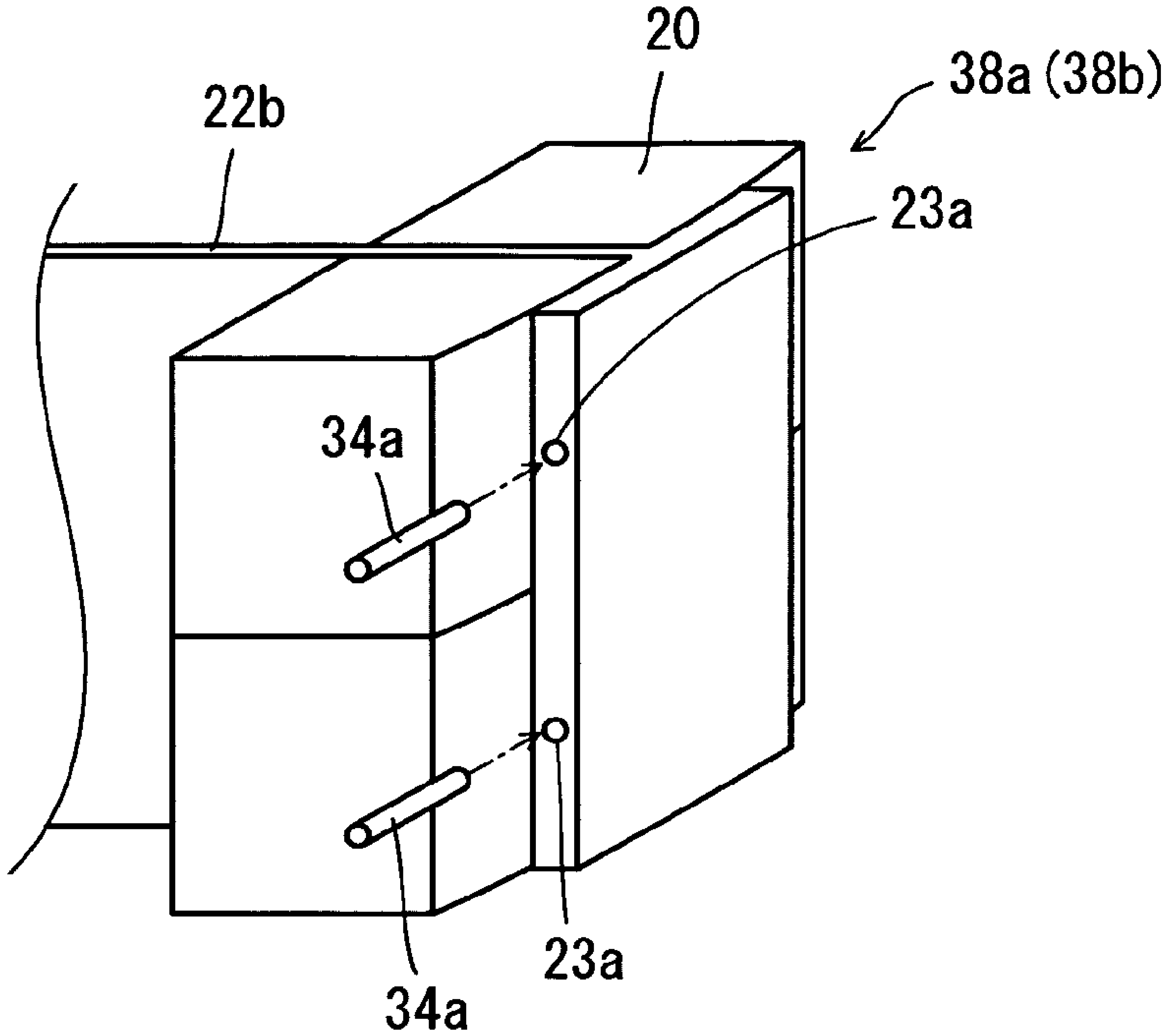
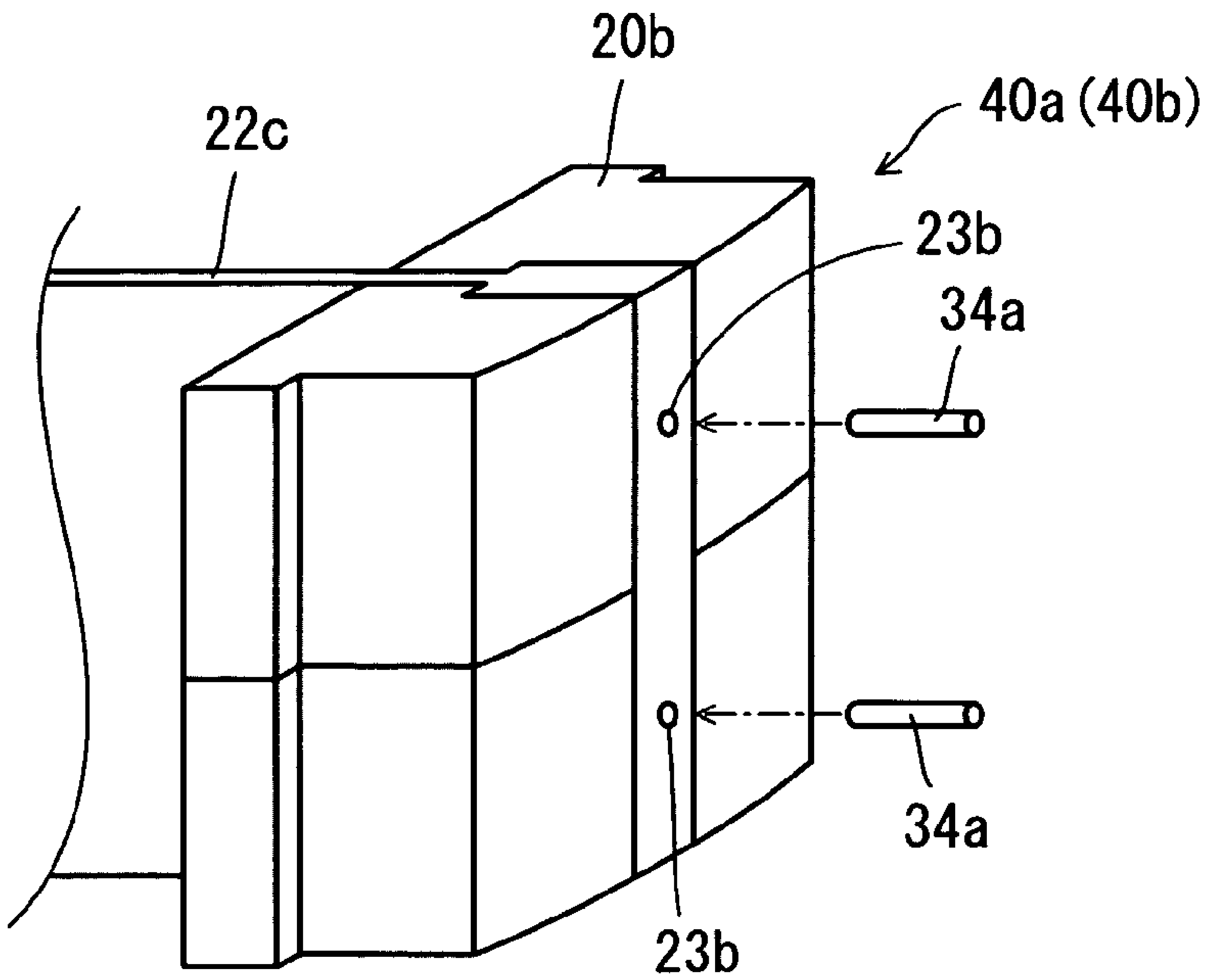


FIG. 6

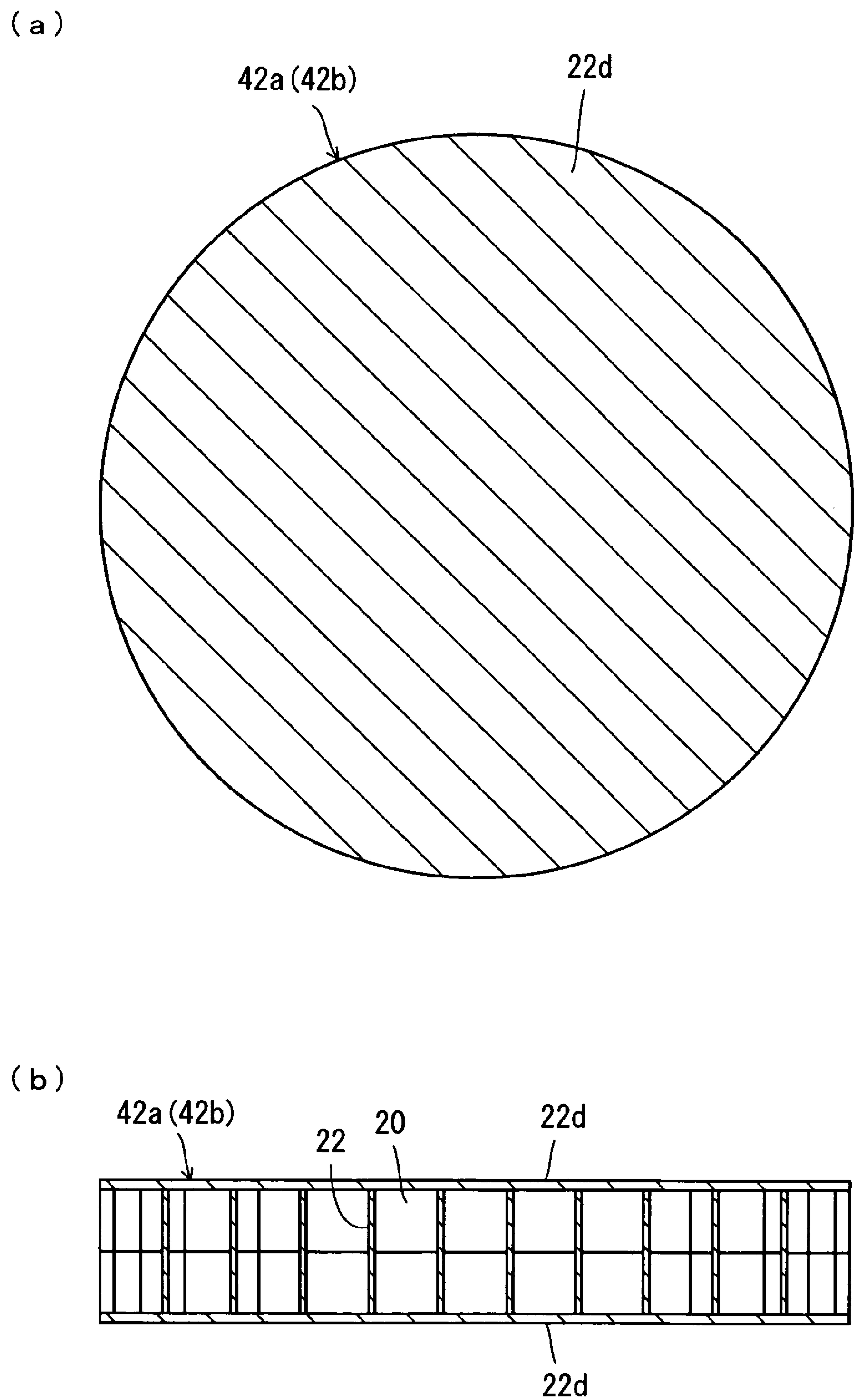
(a)



(b)

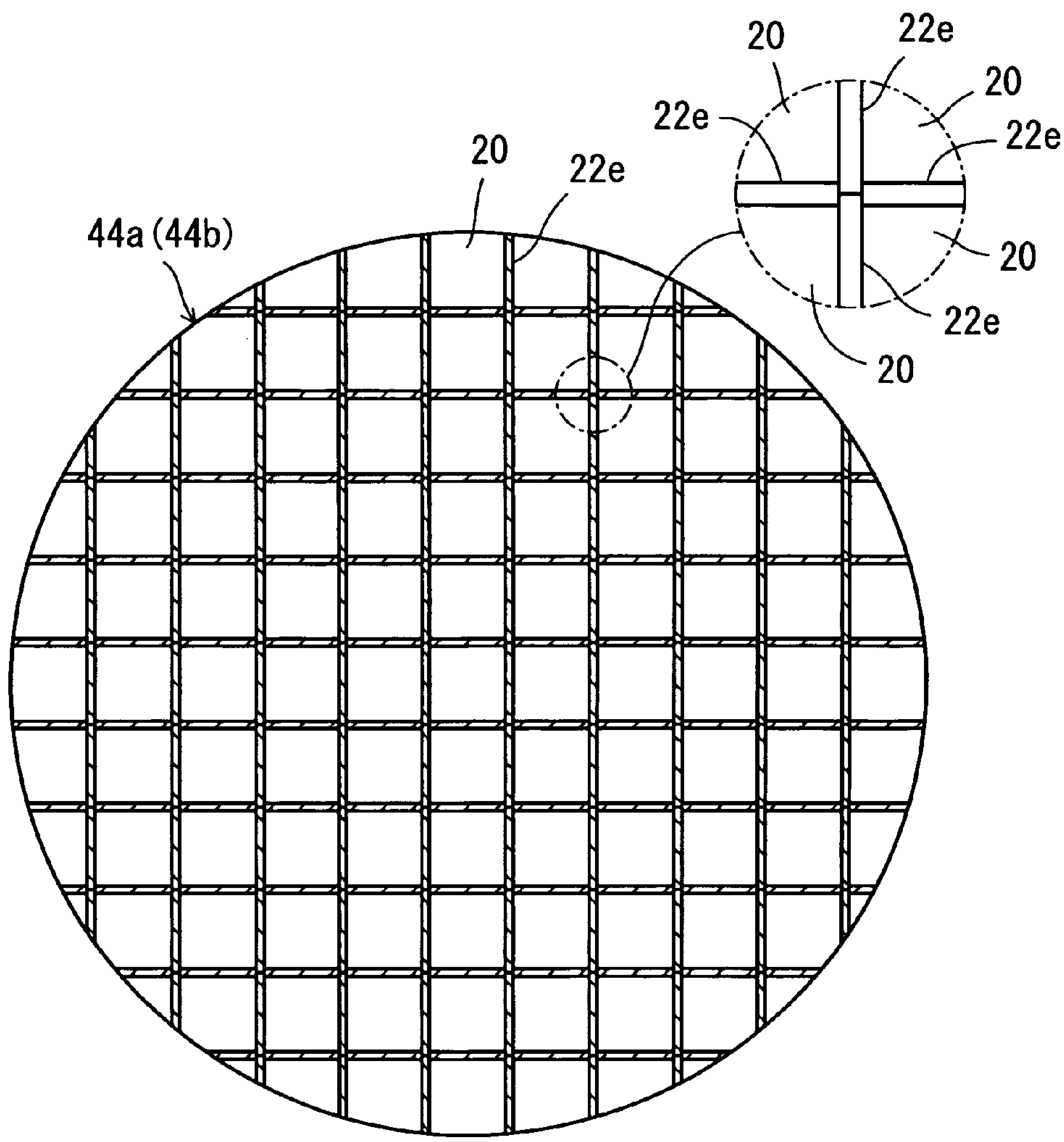


F I G. 7



F I G. 8

(a)


20
22e
20
22e
22e
20
20
22e
20
22e
20
44a (44b)

(b)

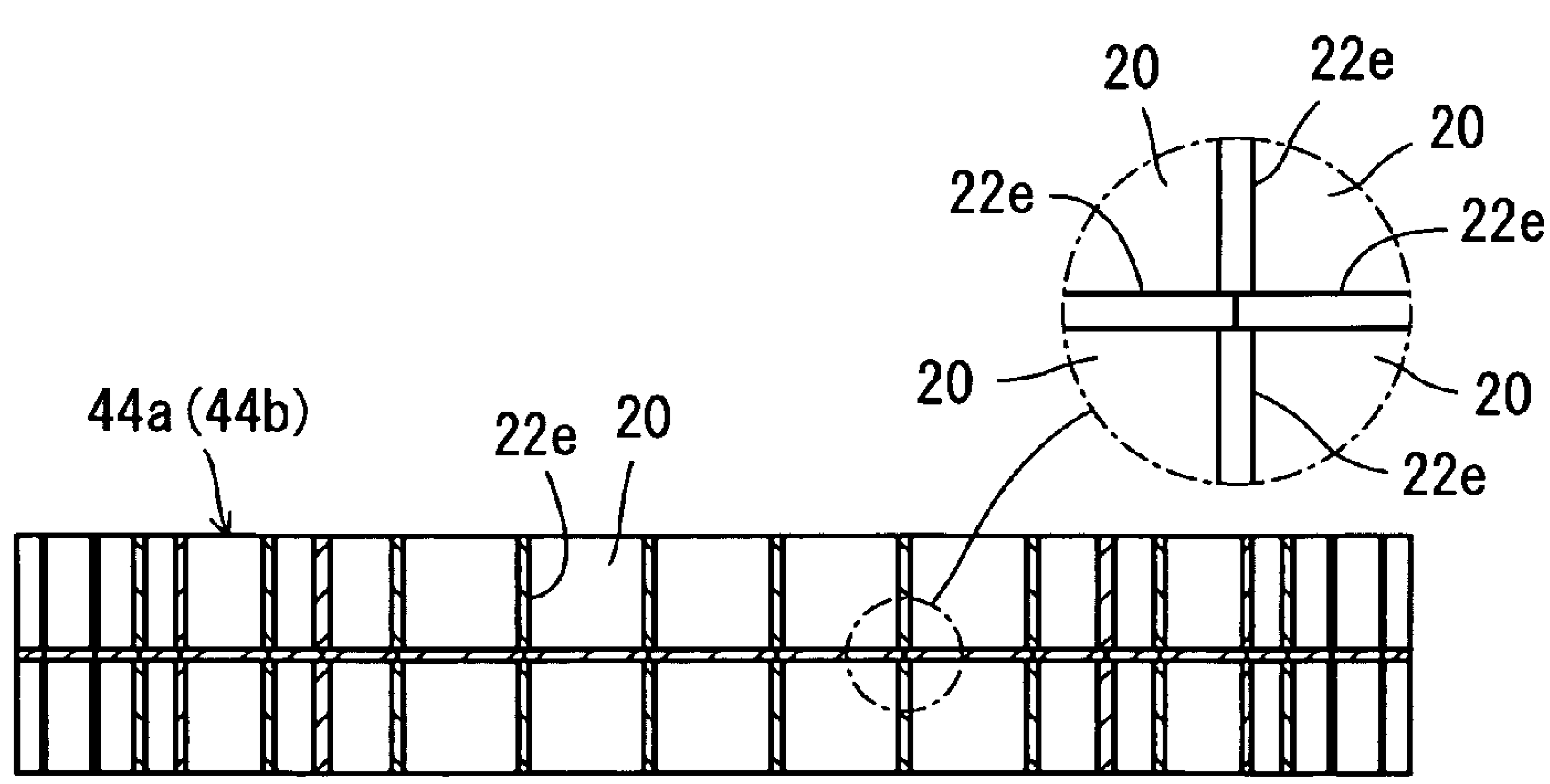
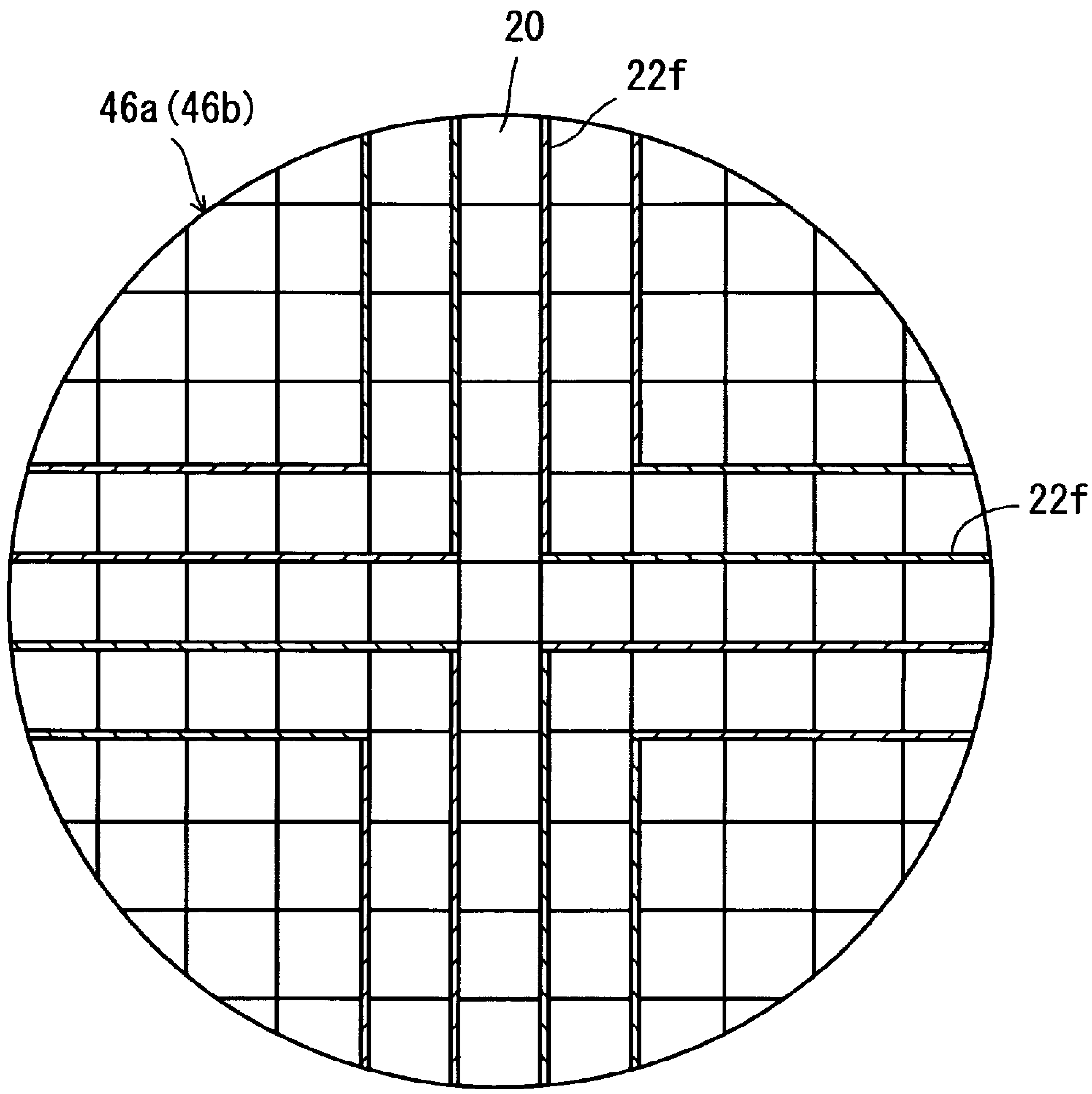
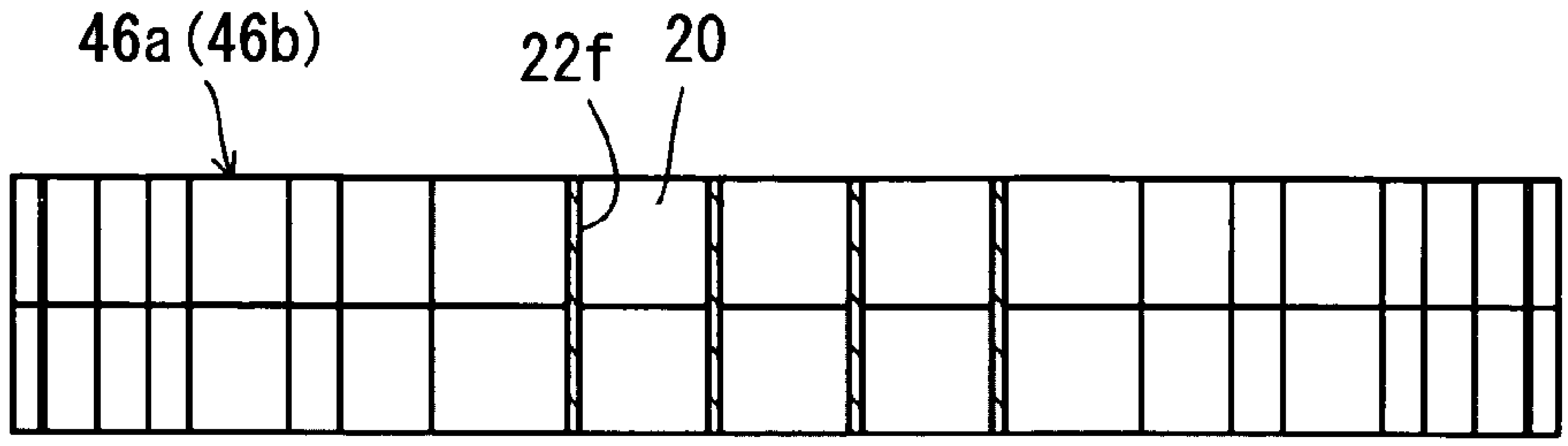

20
22e
20
22e
22e
20
20
22e
44a (44b)
22e
20

FIG. 9

(a)



(b)



F I G. 1 0

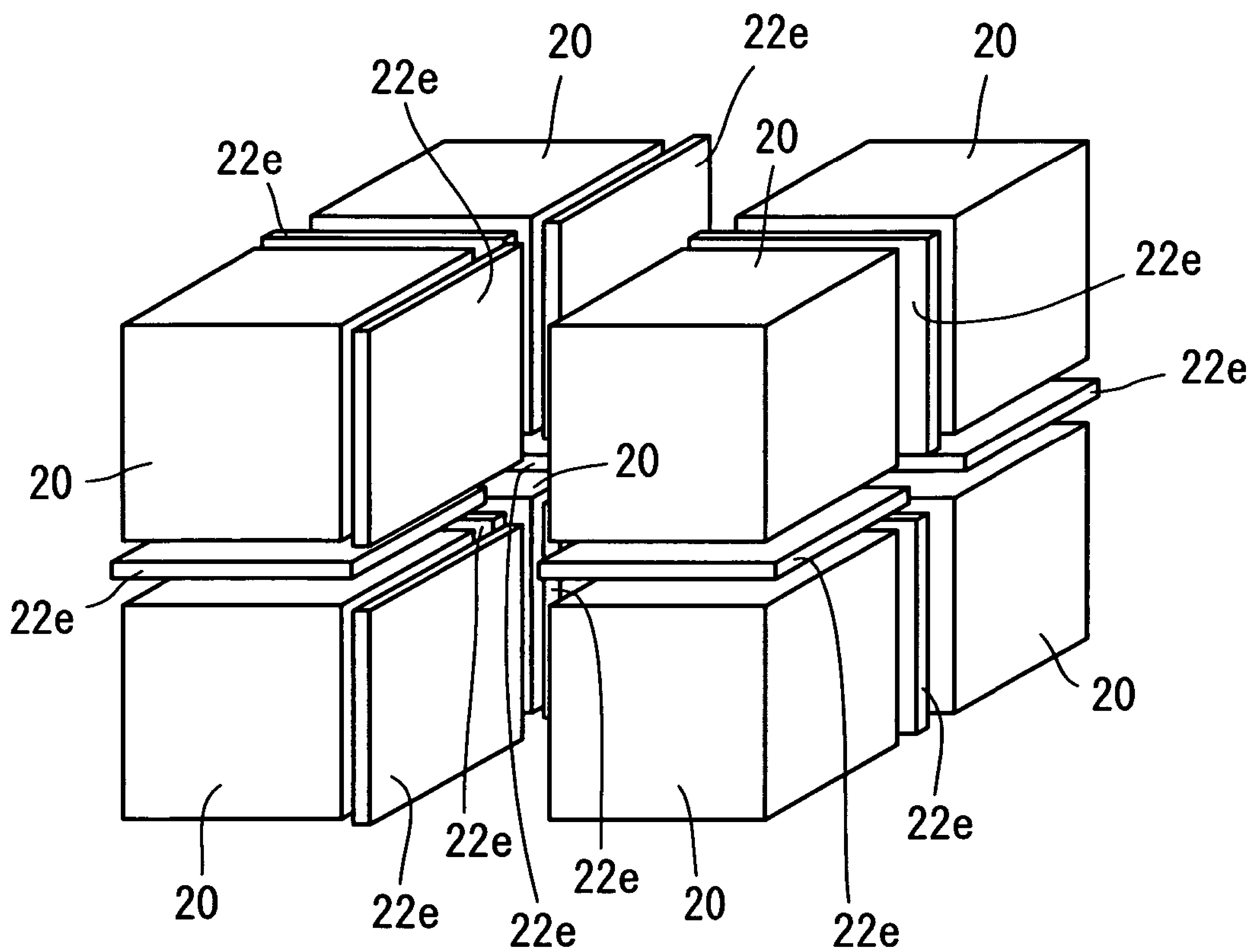
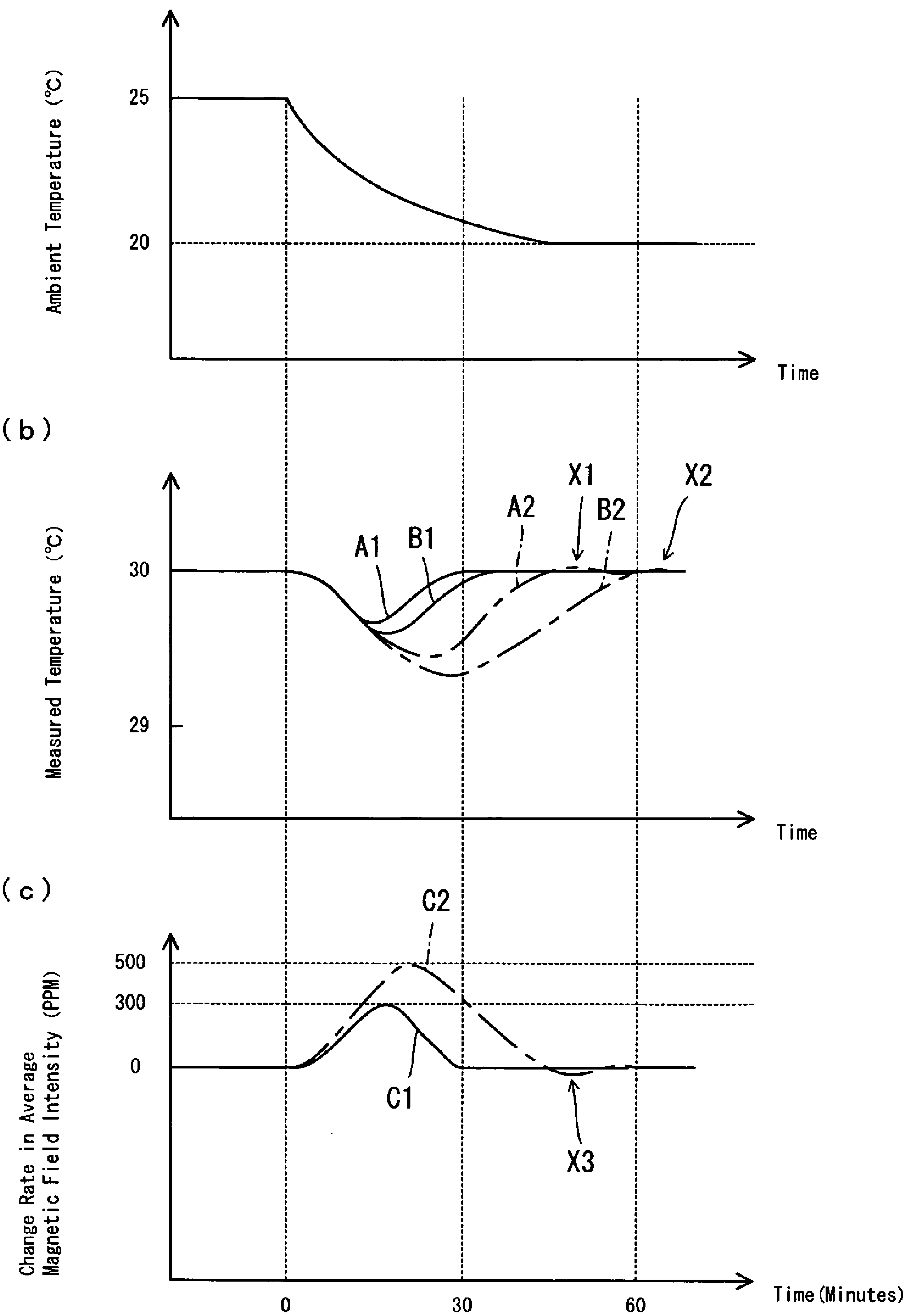

20
22e
22e
20
22e
20
20
22e
20
22e
20
22e
20
22e
22e
20
22e
22e
22e
20
22e

FIG. 11

(a)

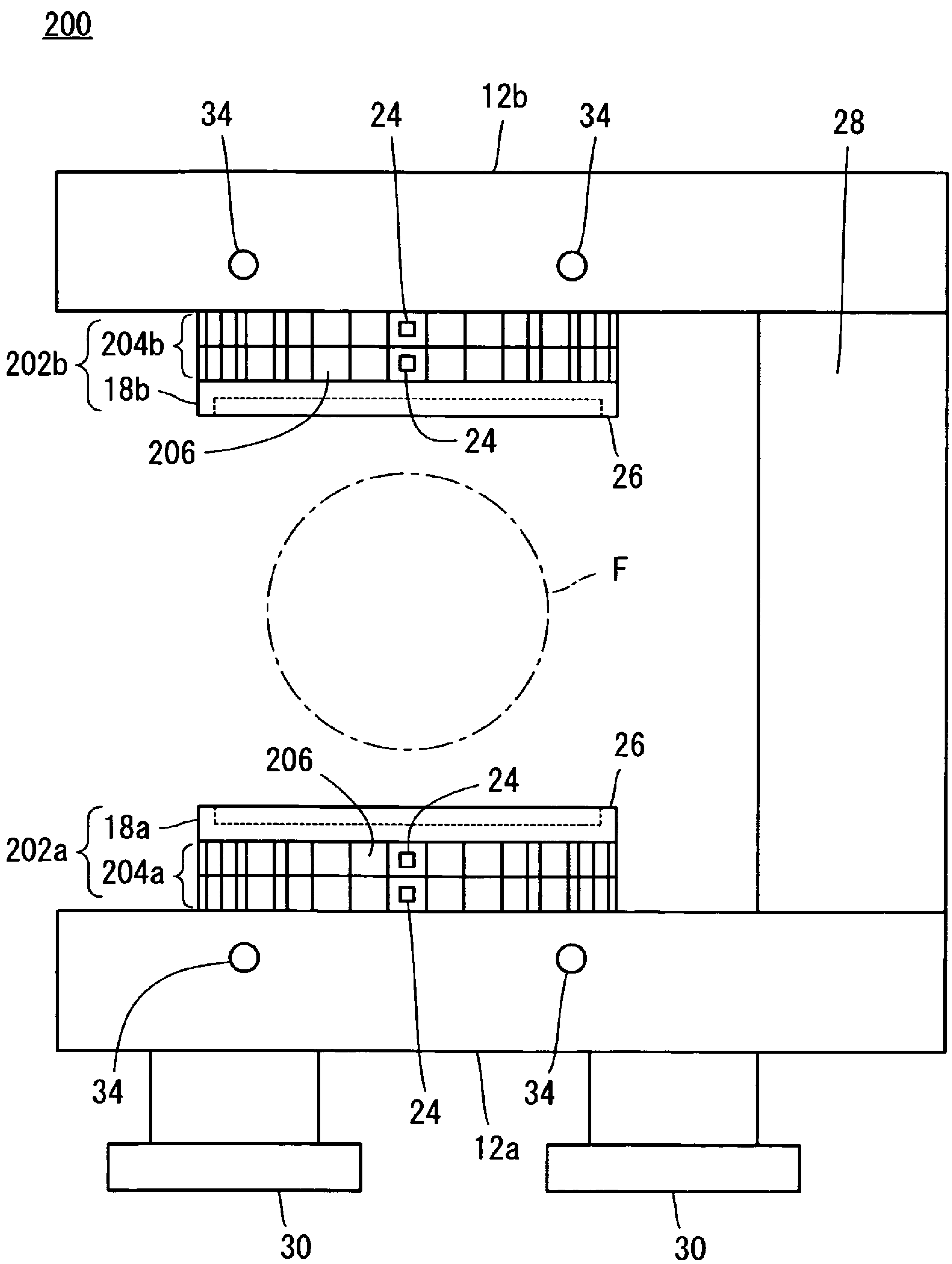
(b)

(c)

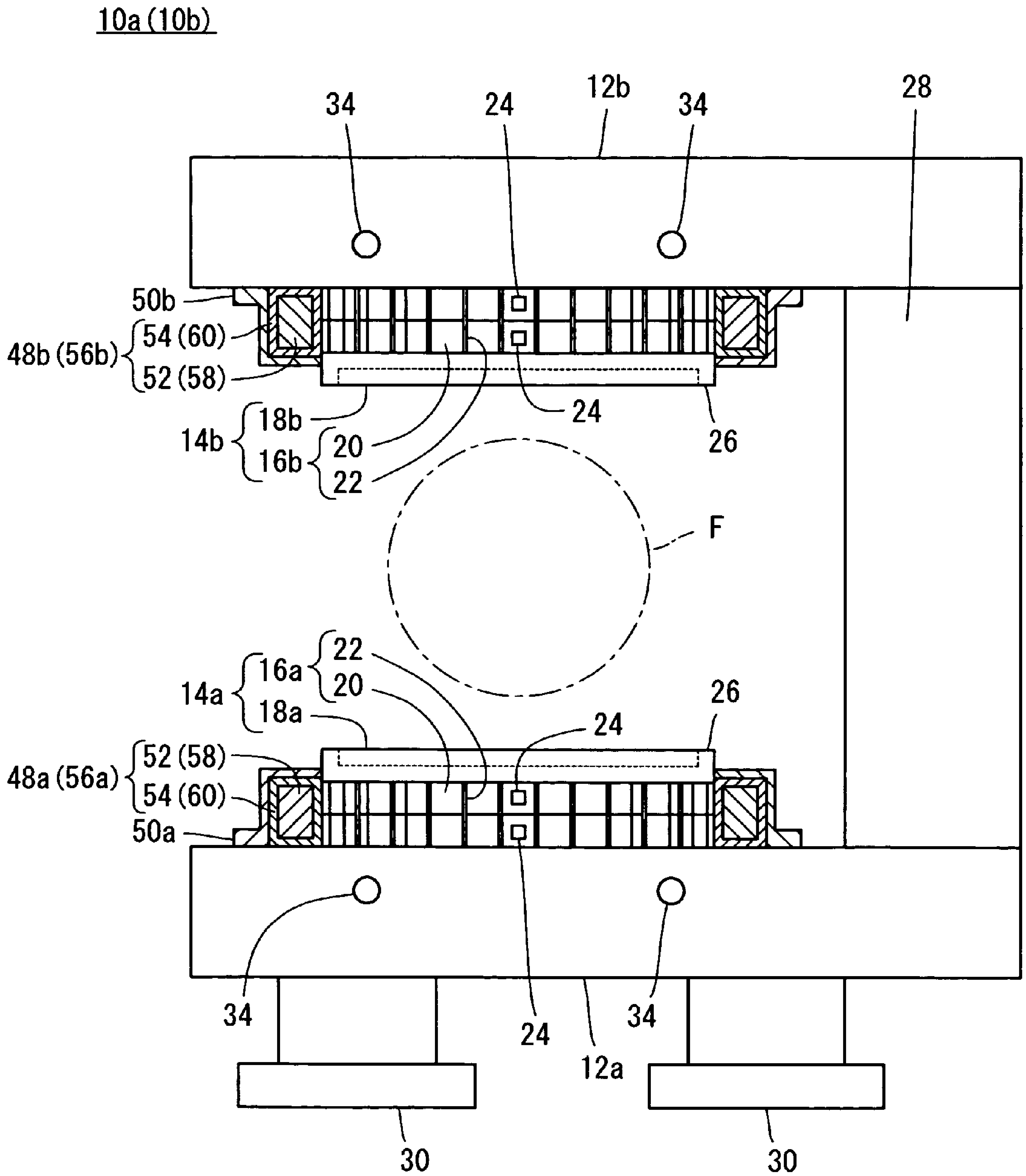


Ambient Temperature (°C)
25
20
Time
Measured Temperature (°C)
30
29
A1
B1
A2
X1
B2
X2
Time
Change Rate in Average Magnetic Field Intensity (PPM)
500
300
0
C2
C1
X3
0
30
60
Time (Minutes)

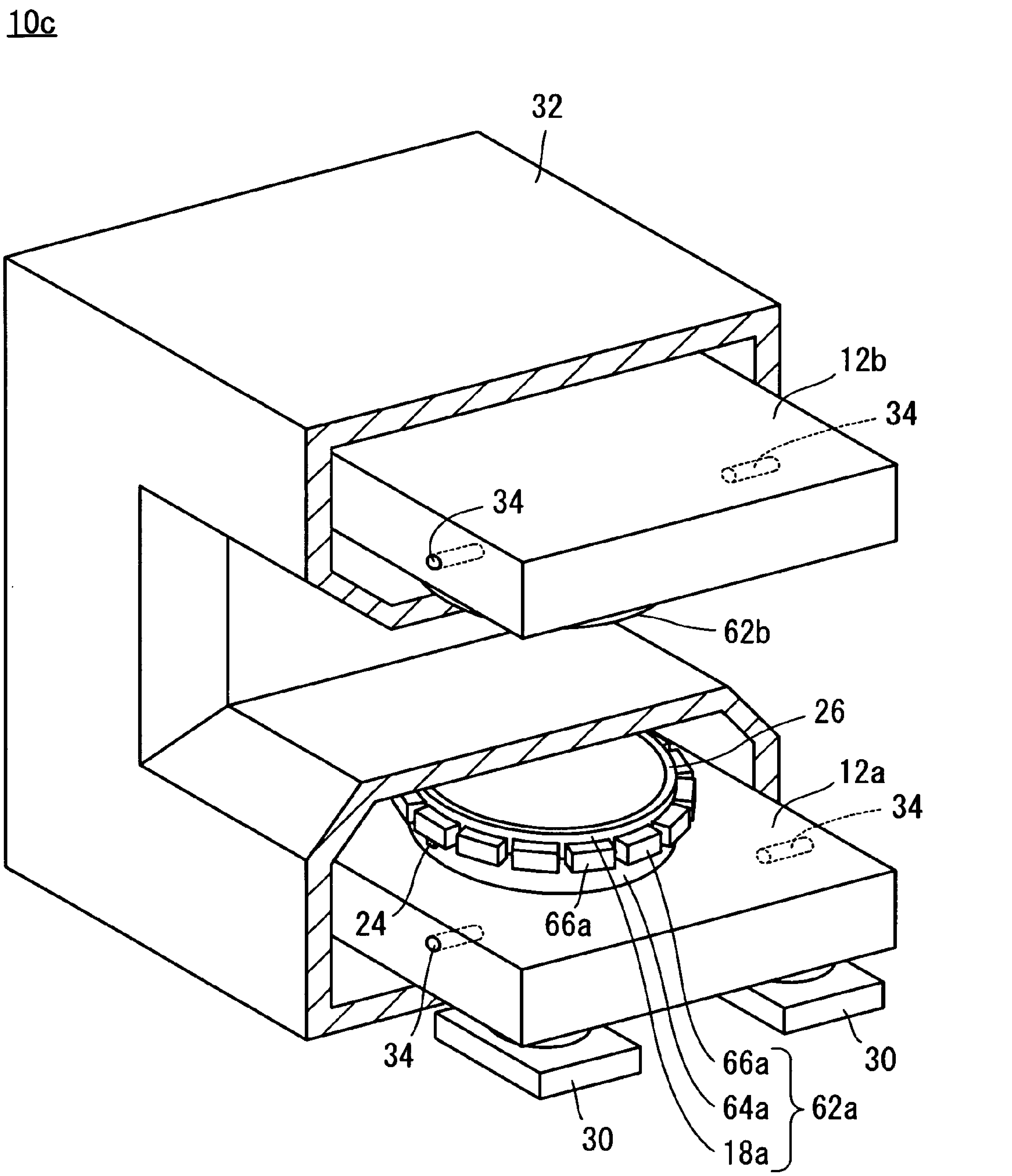
FIG. 12


200
34
24
12b
34
28
202b
204b
18b
206
24
26
F
206
24
26
202a
18a
204a
34
24
34
12a
30
30

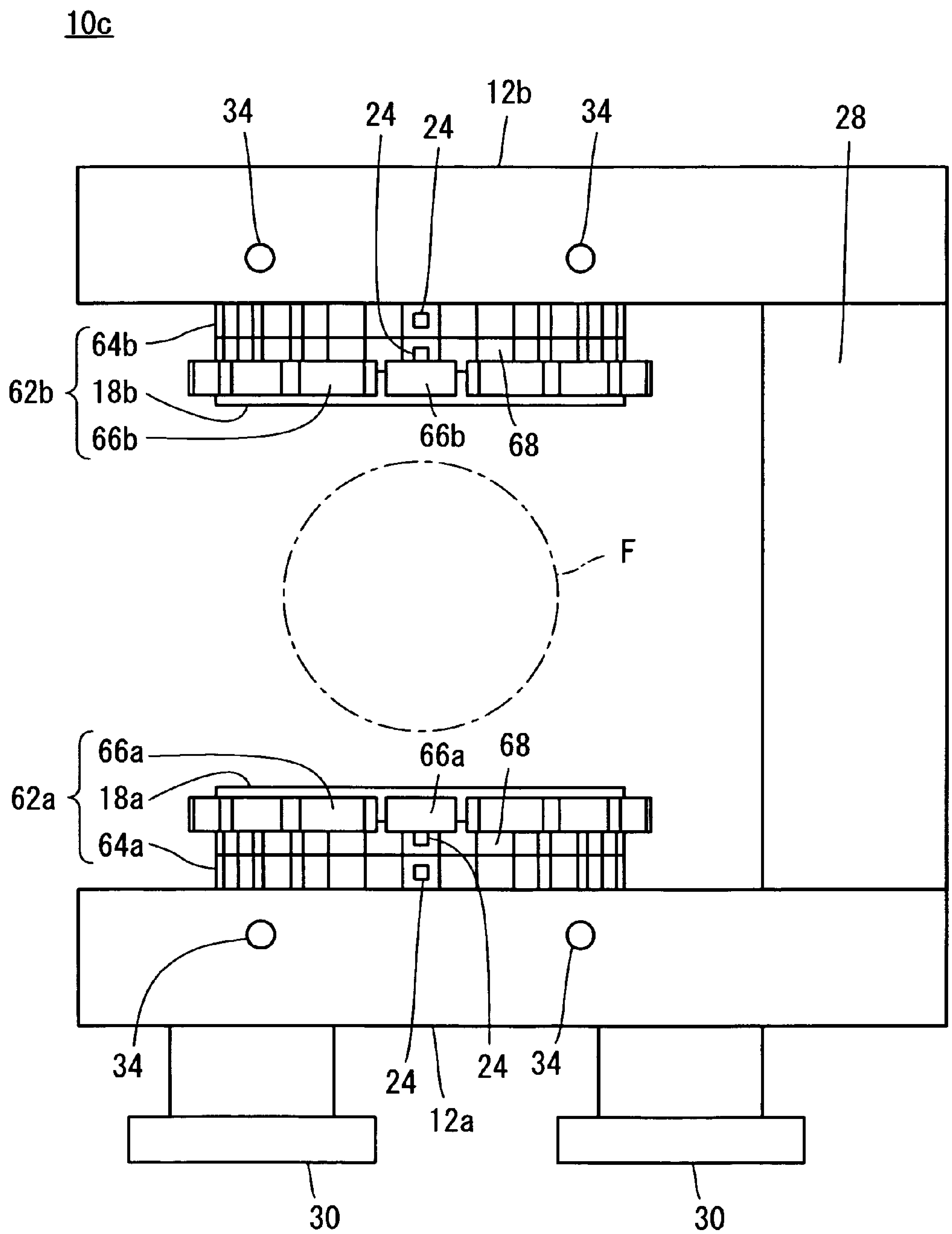
F I G. 1 3


10a (10b)
34
24
12b
34
28
50b
54 (60)
48b (56b)
52 (58)
24
18b
14b
16b
20
22
26
F
22
16a
14a
20
18a
26
24
52 (58)
48a (56a)
54 (60)
50a
34
24
12a
34
30
30

F I G. 14

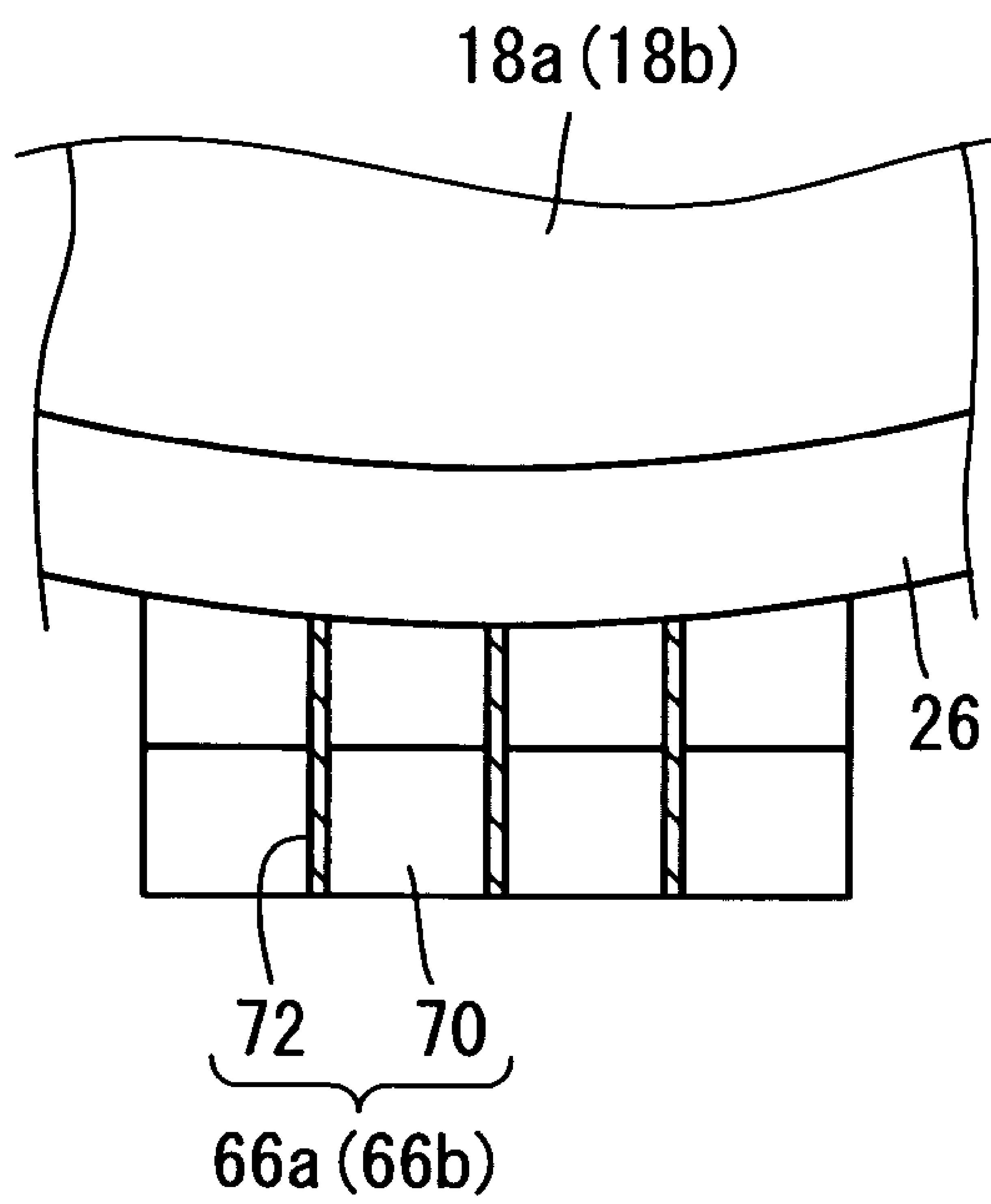


F I G. 15

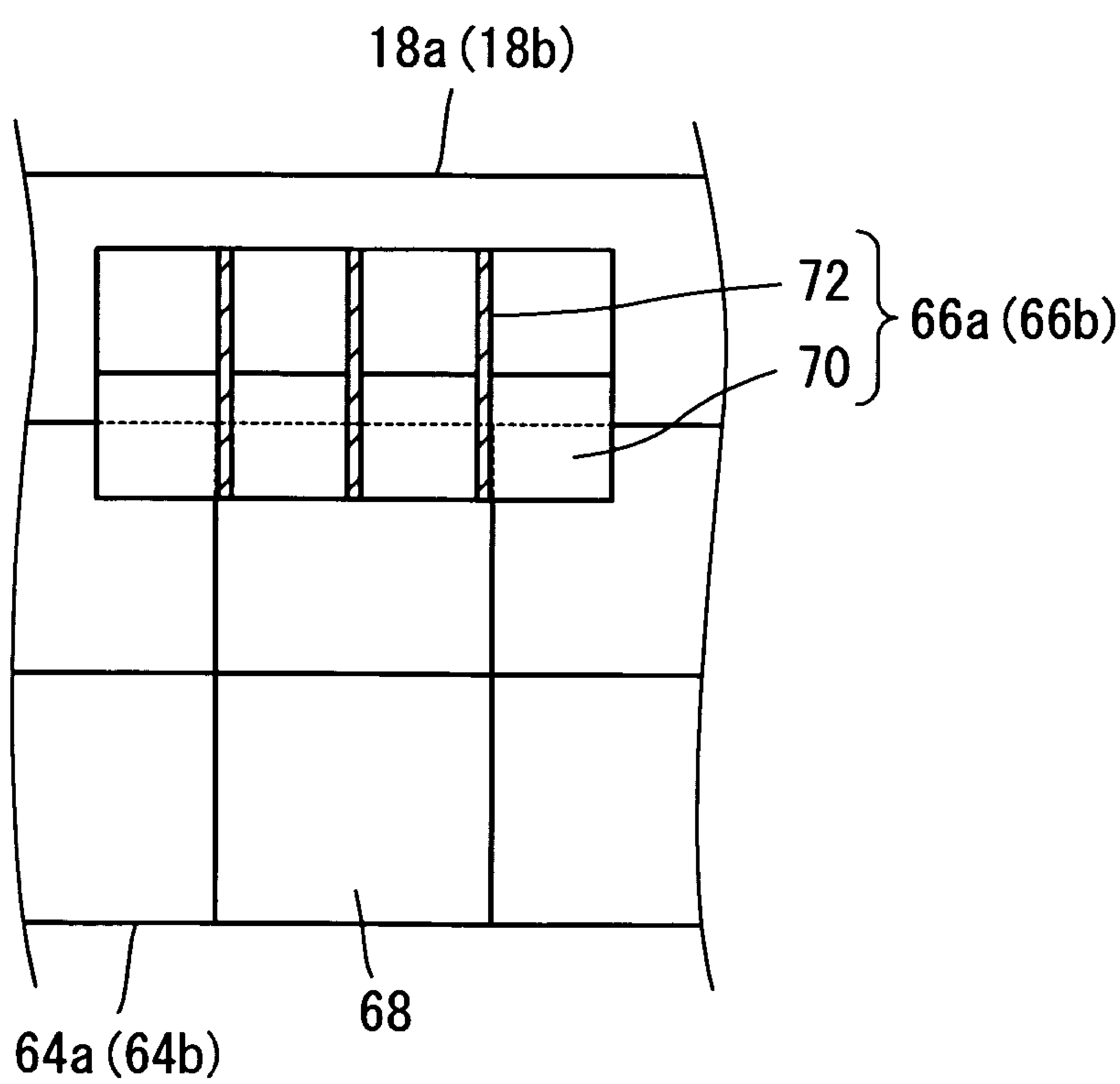

10c
34
24
24
12b
34
28
64b
62b
18b
66b
66b
68
F
66a
66a
68
62a
18a
64a
34
24
24
34
12a
30
30

F I G. 1 6

(a)

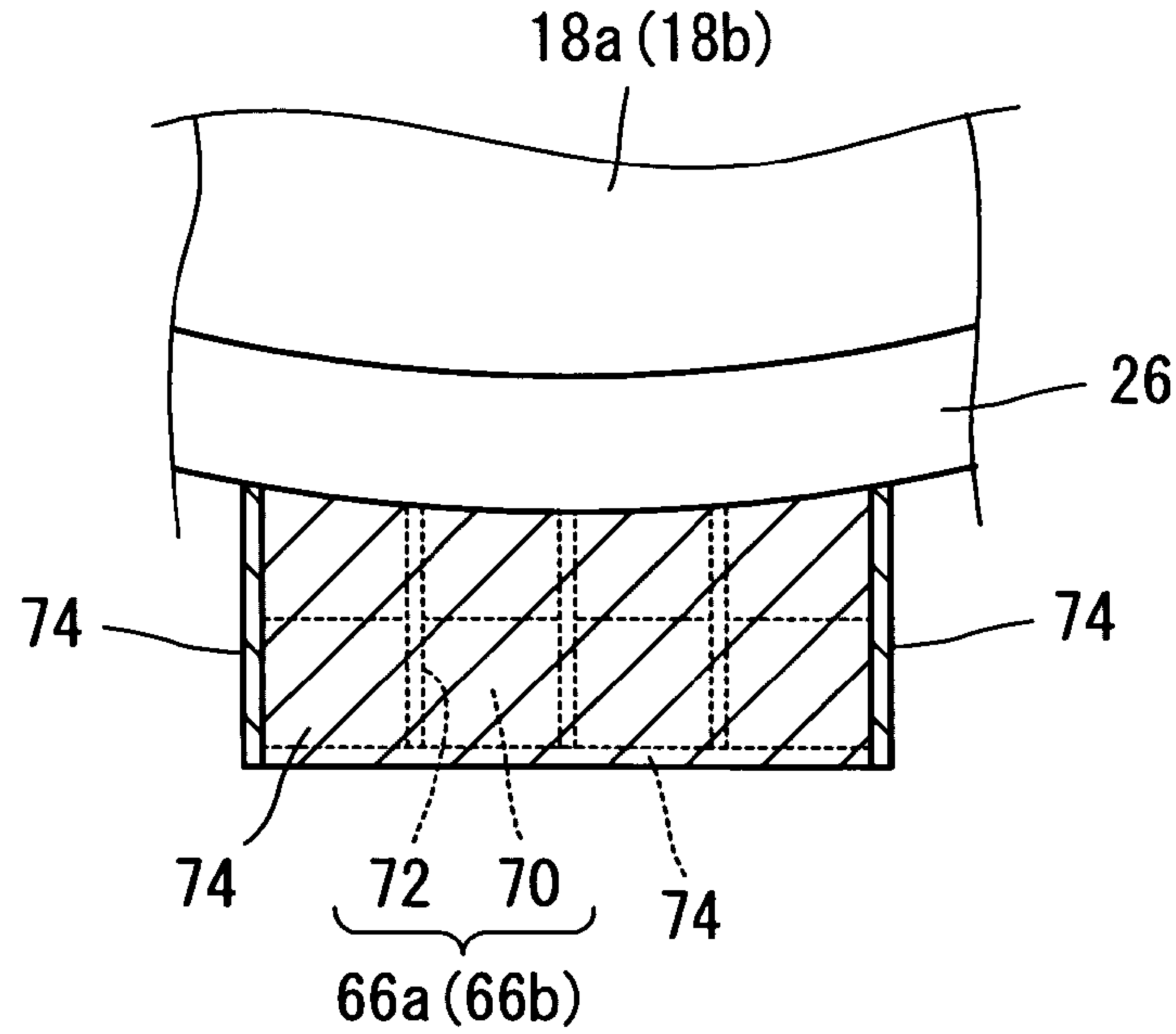


(b)

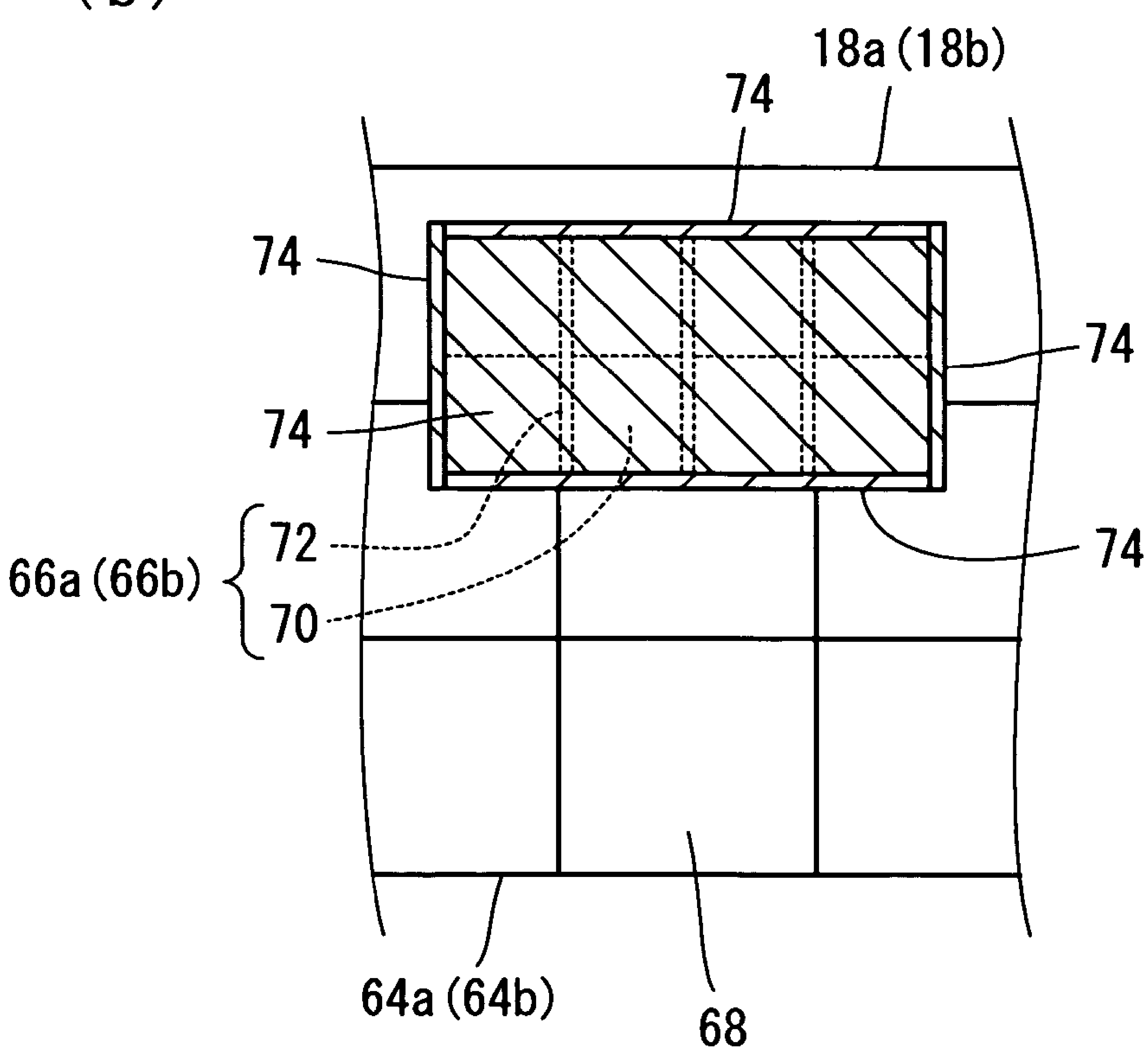


F I G. 1 7

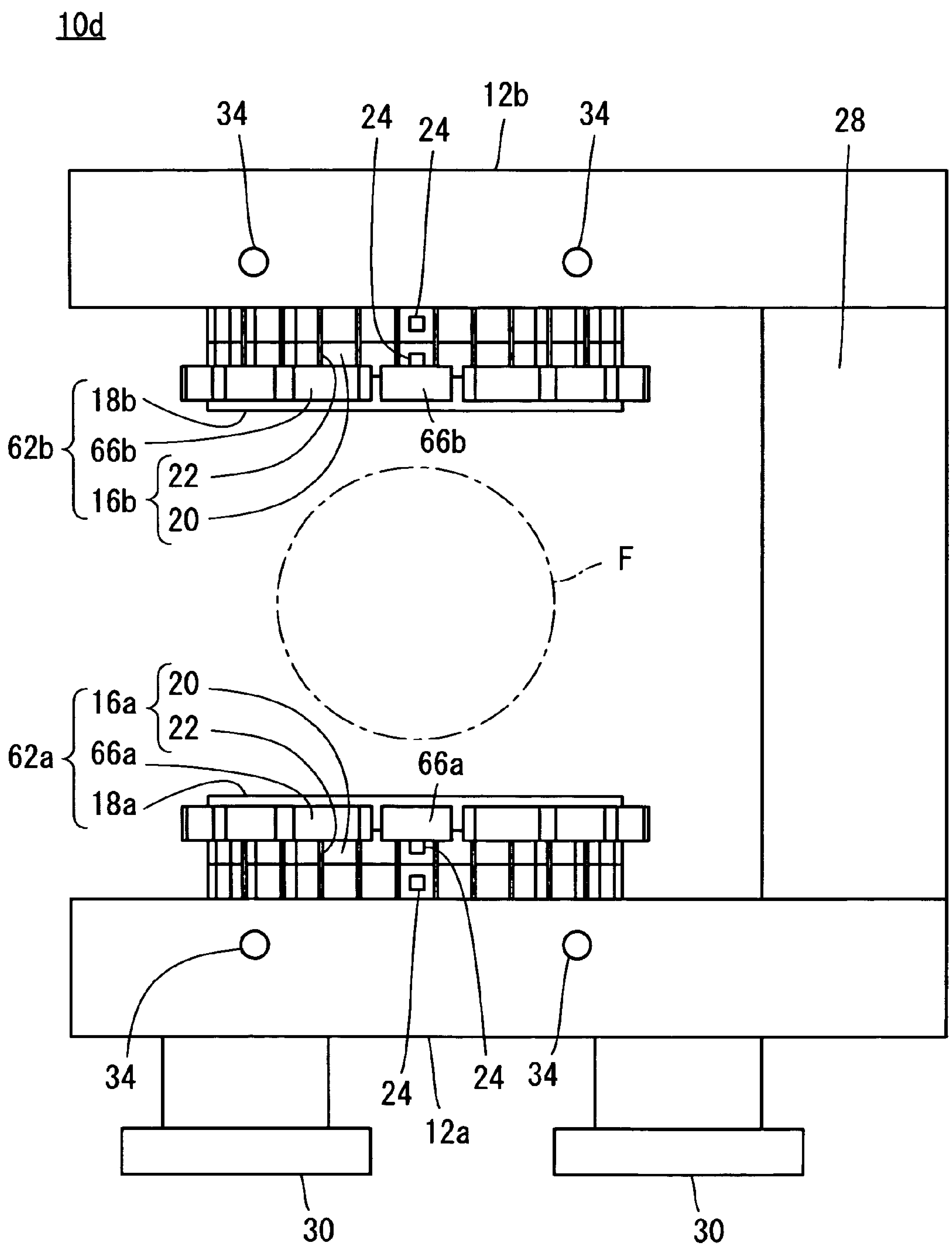
(a)


18a (18b)
26
74
74
74
72
70
74
66a (66b)

(b)


18a (18b)
74
74
74
74
74
66a (66b)
72
70
64a (64b)
68

F I G. 1 8


10d
34
24
24
12b
34
28
62b
18b
66b
22
16b
20
66b
F
20
16a
22
62a
66a
18a
66a
34
24
12a
24
34
30
30

F I G. 19

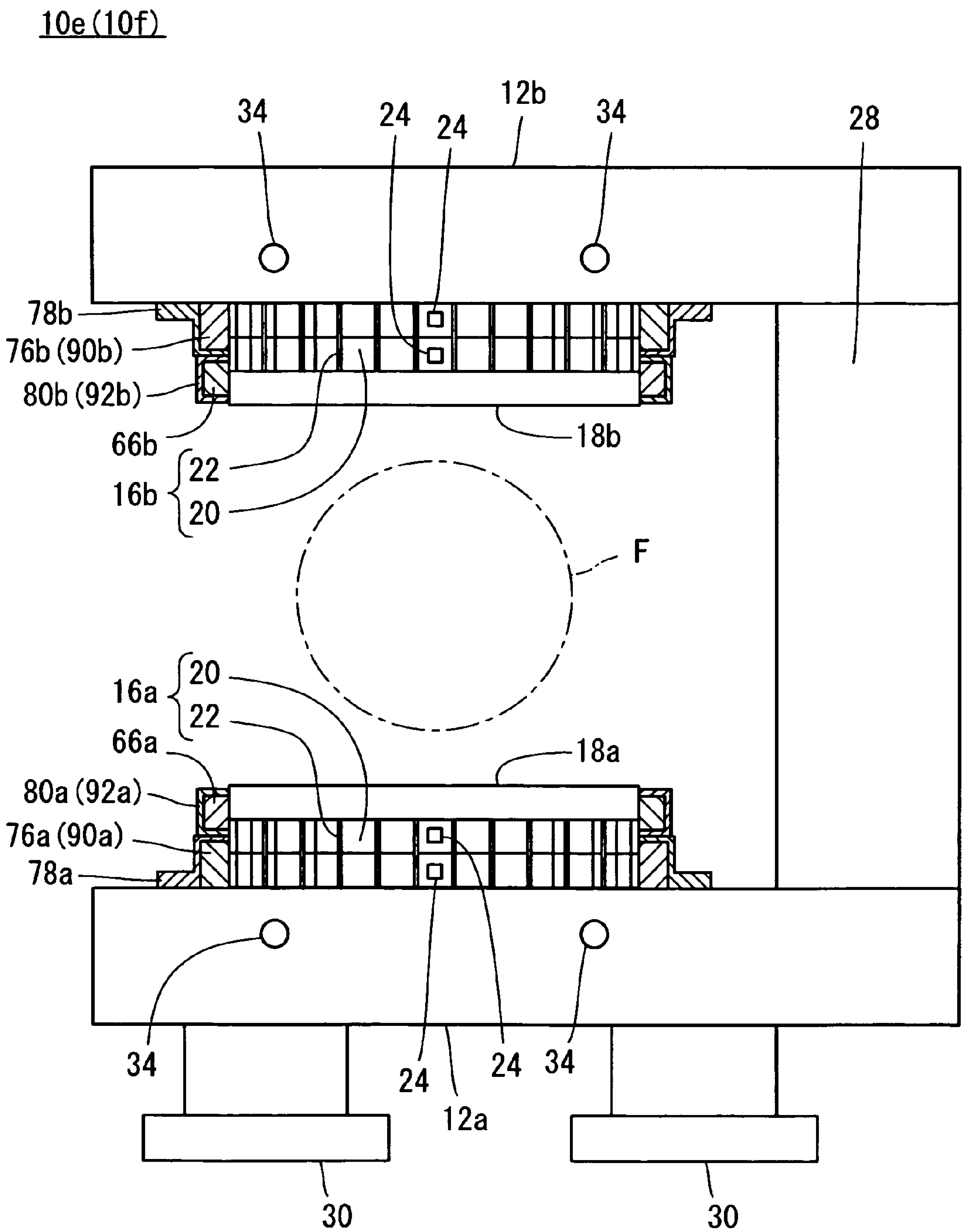
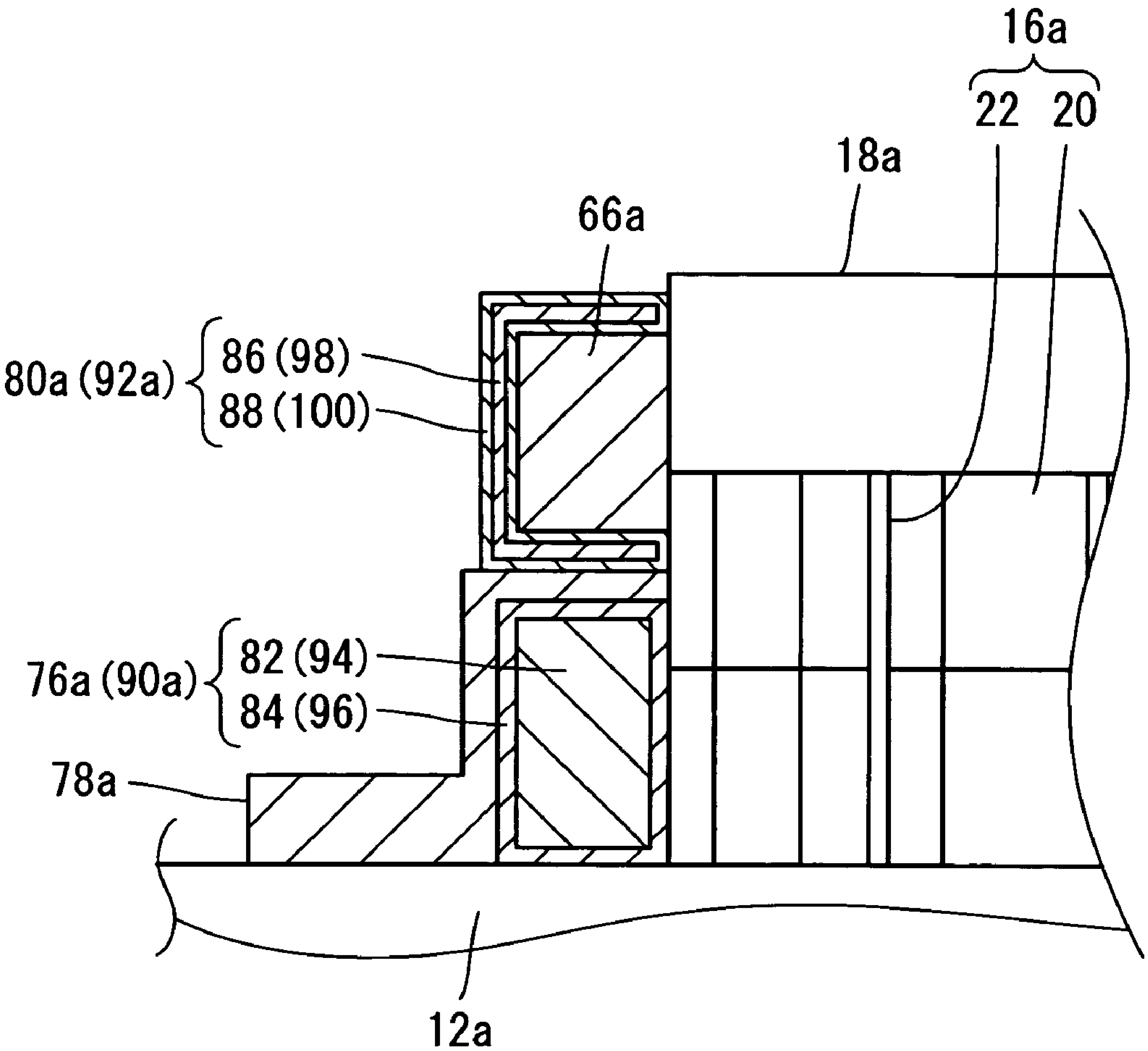
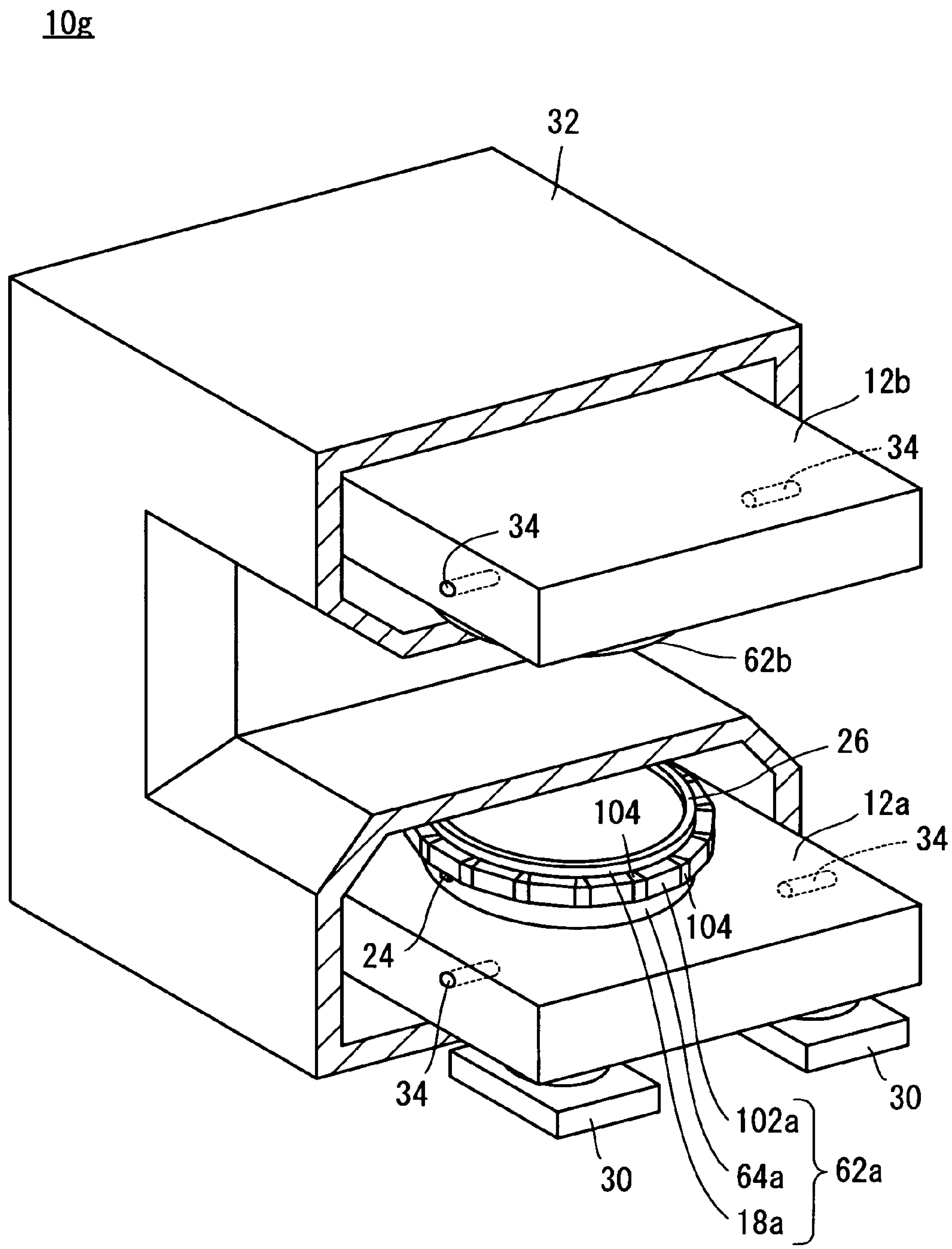

10e (10f)
34
24
24
12b
34
28
78b
76b (90b)
80b (92b)
66b
18b
16b
22
20
F
16a
20
22
66a
18a
80a (92a)
76a (90a)
78a
34
24
24
34
12a
30
30

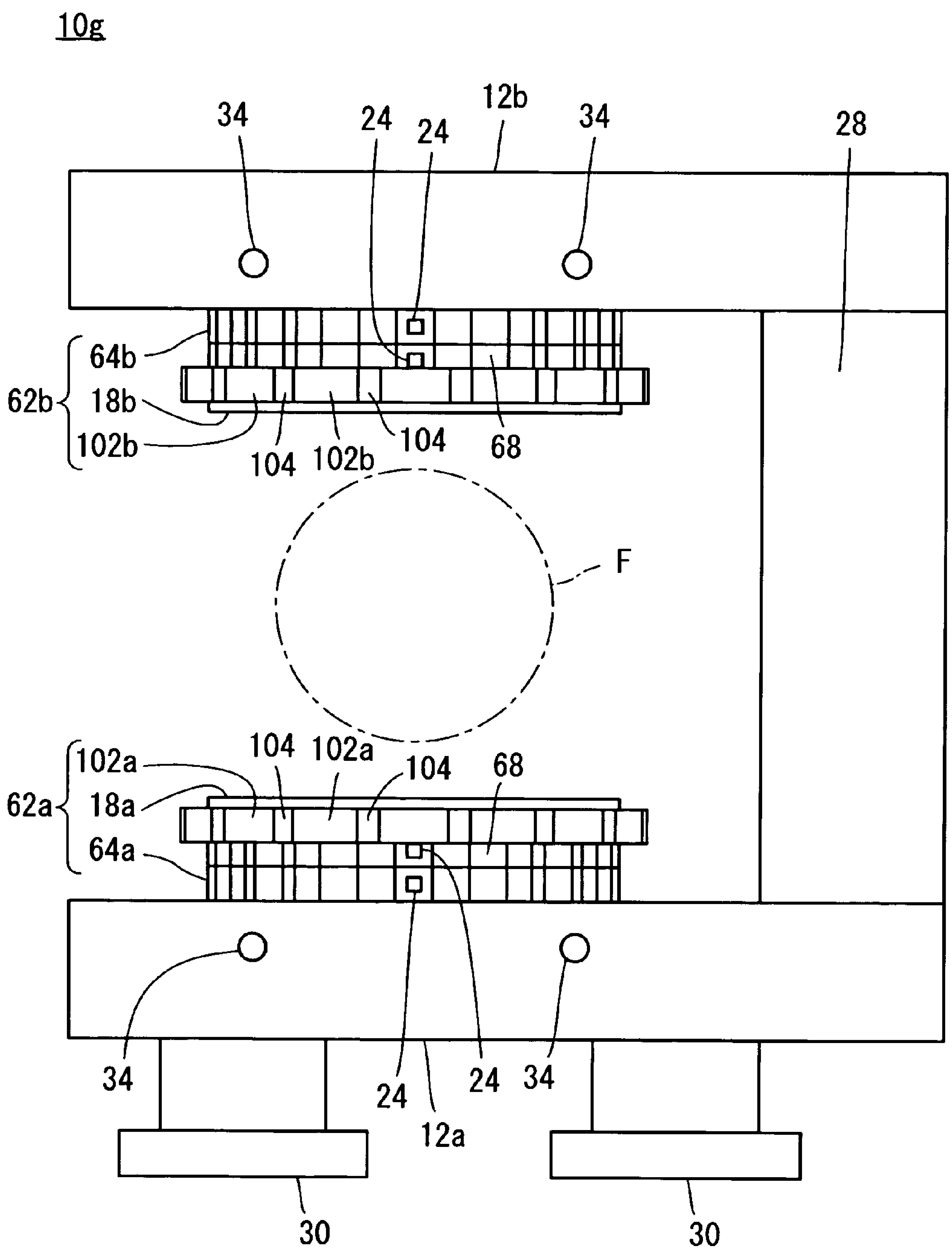
FIG. 20



F I G. 2 1

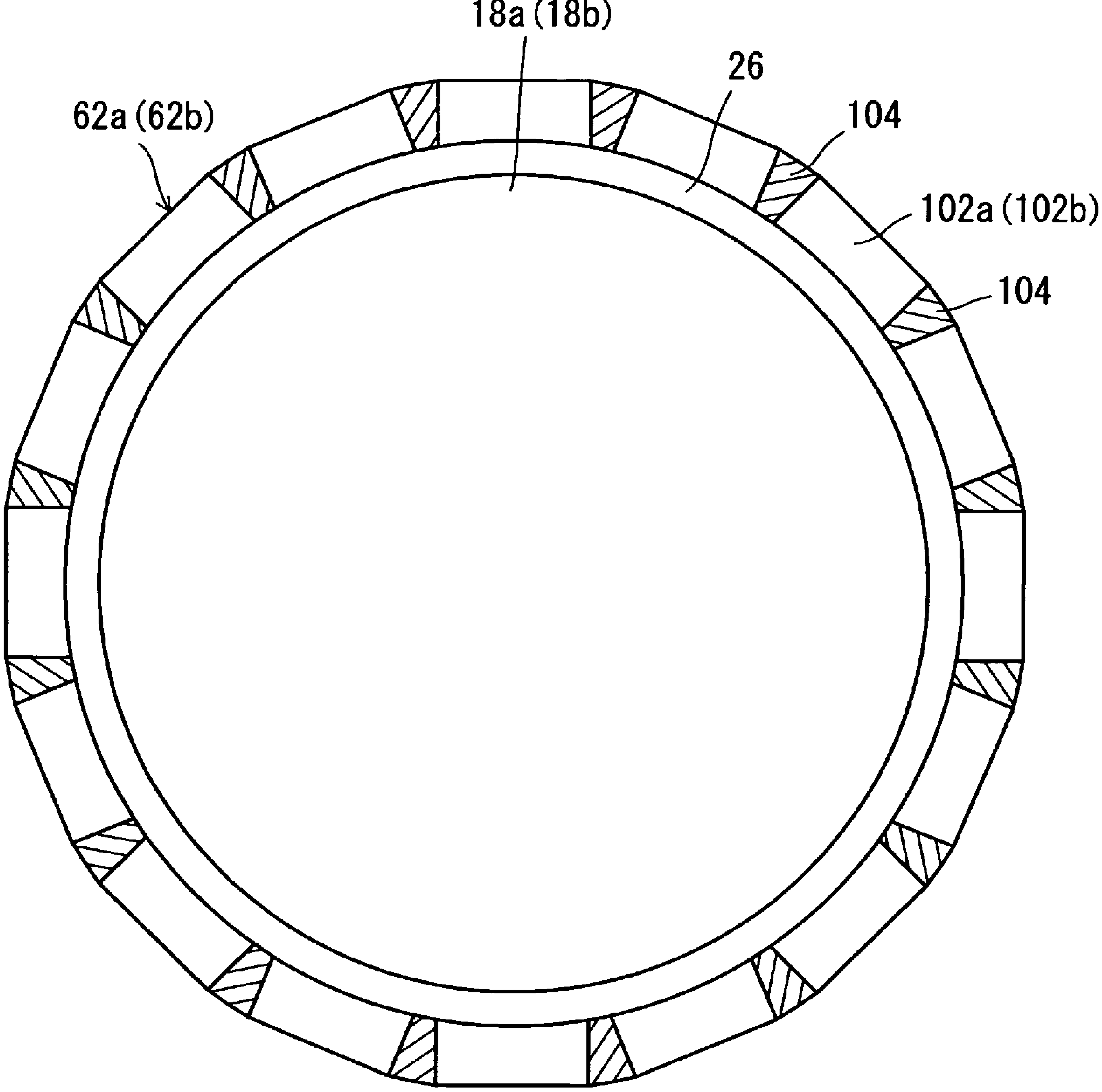


F I G. 2 2

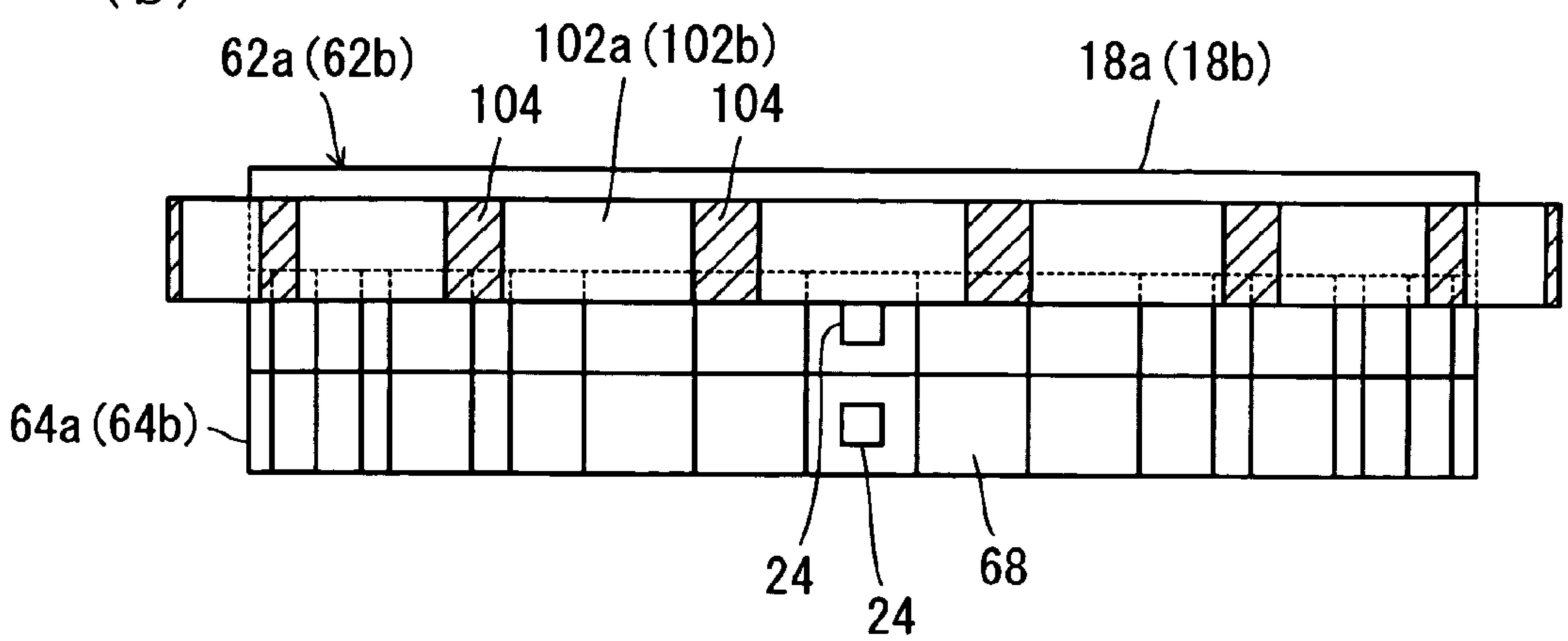

10g
34
24
24
12b
34
28
64b
62b
18b
102b
104
102b
104
68
F
102a
104
102a
104
68
62a
18a
64a
34
24
24
34
12a
30
30

F I G. 2 3

(a)


18a (18b)
26
62a (62b)
104
102a (102b)
104

(b)


62a (62b)
102a (102b)
104
104
18a (18b)
64a (64b)
24
24
68

F I G. 2 4

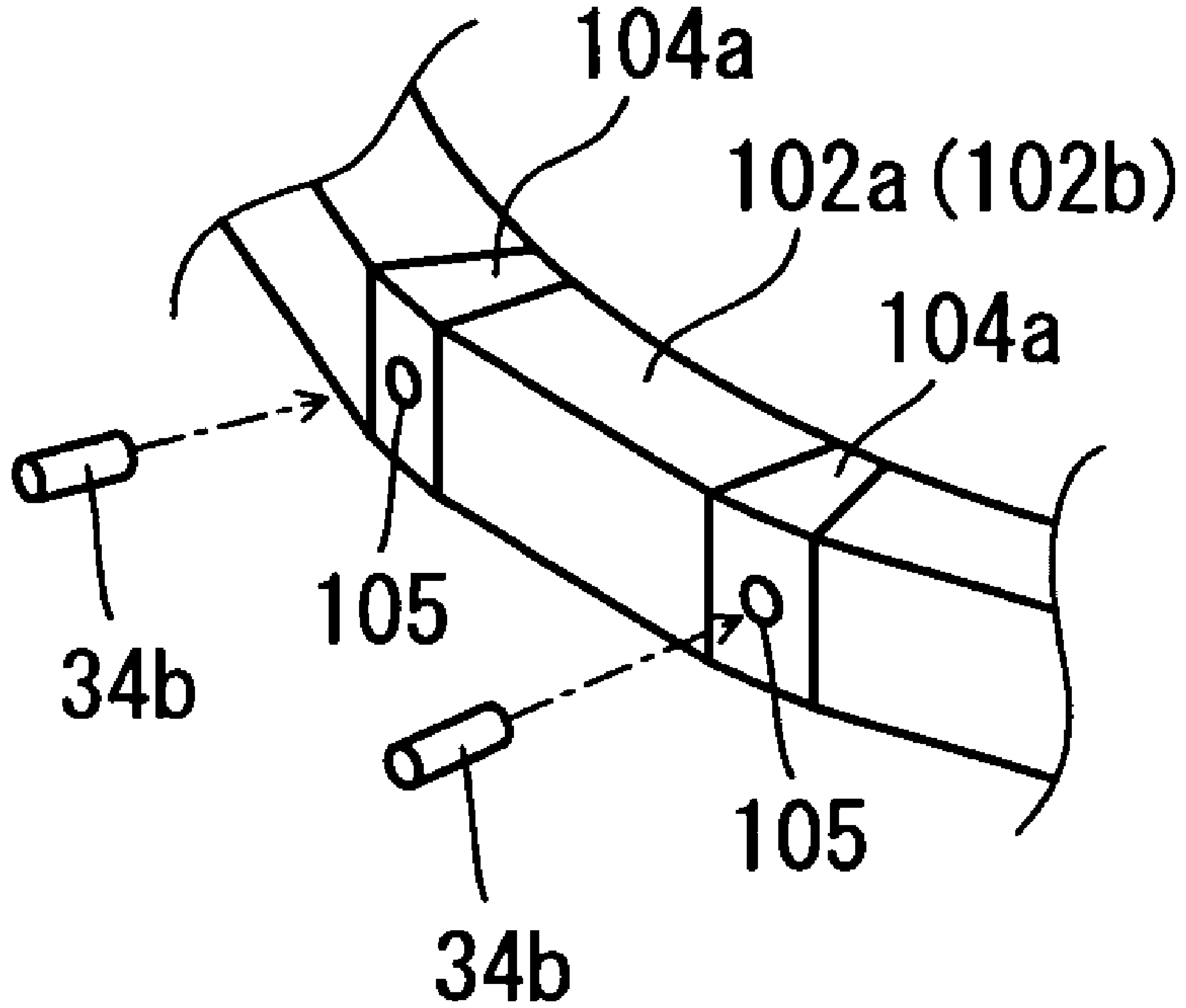
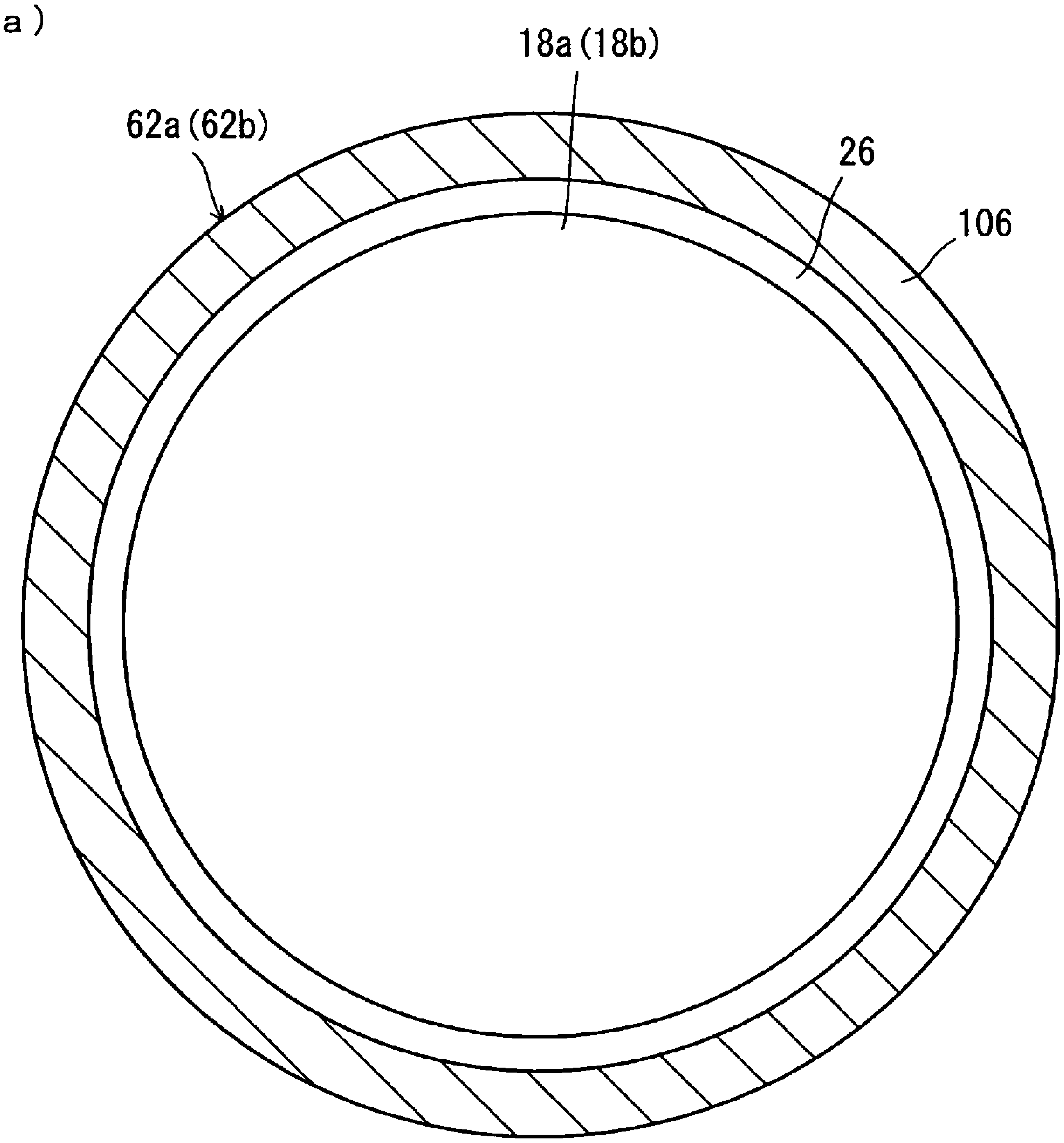
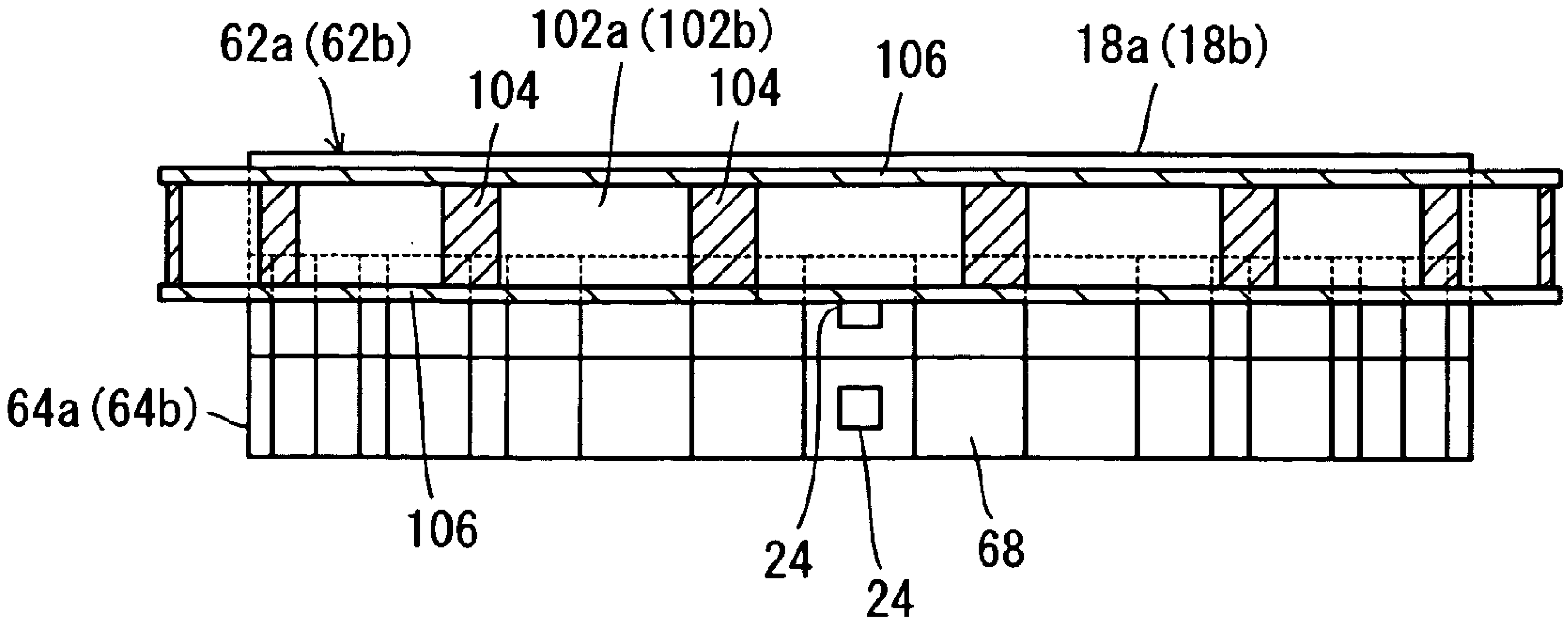


FIG. 25

(a)


18a (18b)
62a (62b)
26
106

(b)


62a (62b)
102a (102b)
104
104
106
18a (18b)
64a (64b)
106
24
24
68

F I G. 2 6

(a)

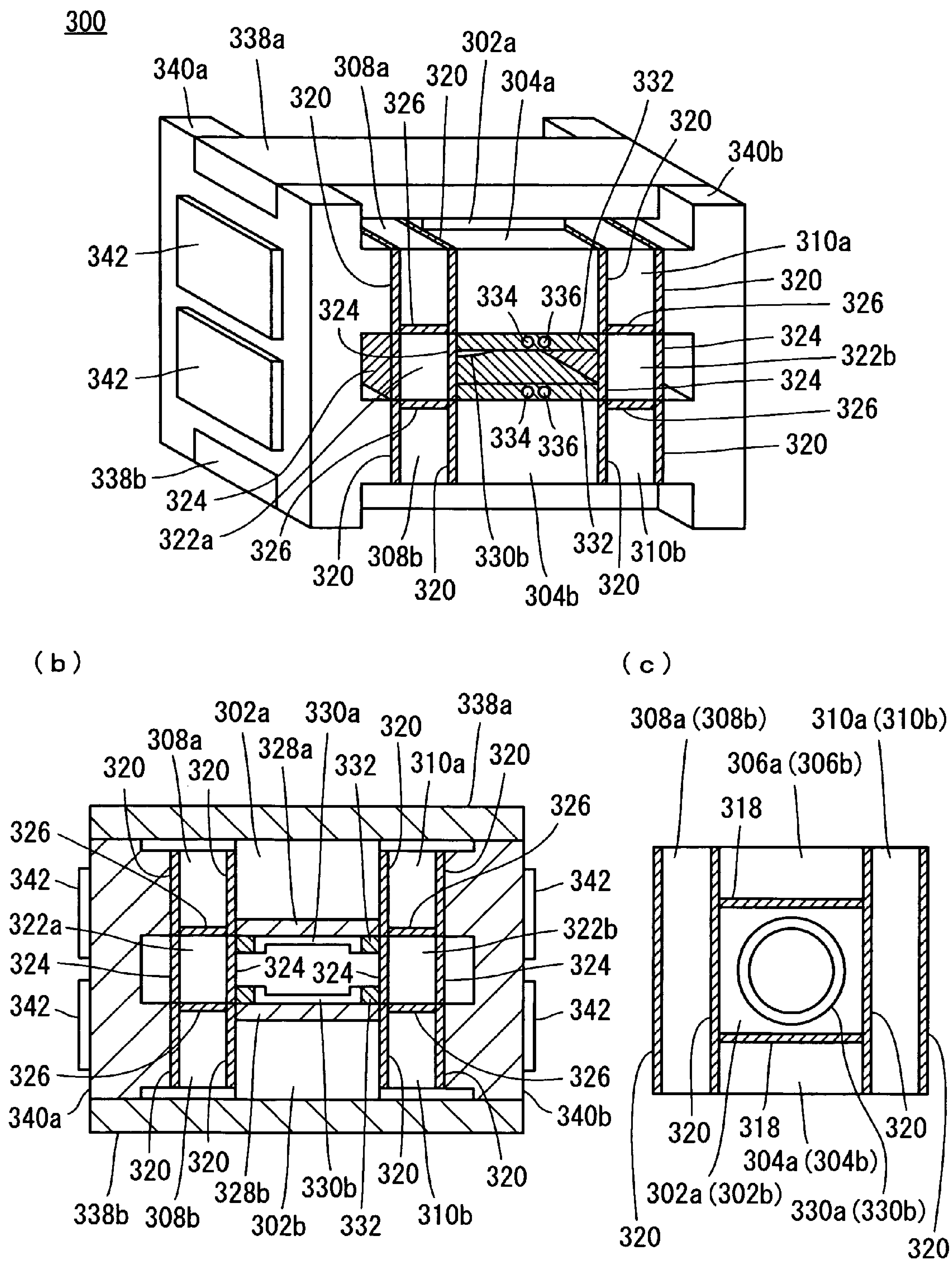

300
338a
302a
340a
308a
320
304a
332
320
326
320
340b
310a
342
320
334
336
326
324
324
322b
324
342
326
334
336
320
338b
324
322a
326
320
308b
330b
332
310b
320
304b
320
(b)
(c)
302a
330a
320
338a
308a
328a
332
310a
320
320
320
326
326
342
342
322a
322b
324
324
324
324
342
342
326
326
340a
340b
320
320
328b
330b
320
320
338b
308b
302b
332
310b
308a (308b)
310a (310b)
306a (306b)
318
320
318
320
304a (304b)
302a (302b)
330a (330b)
320
320

FIG. 27

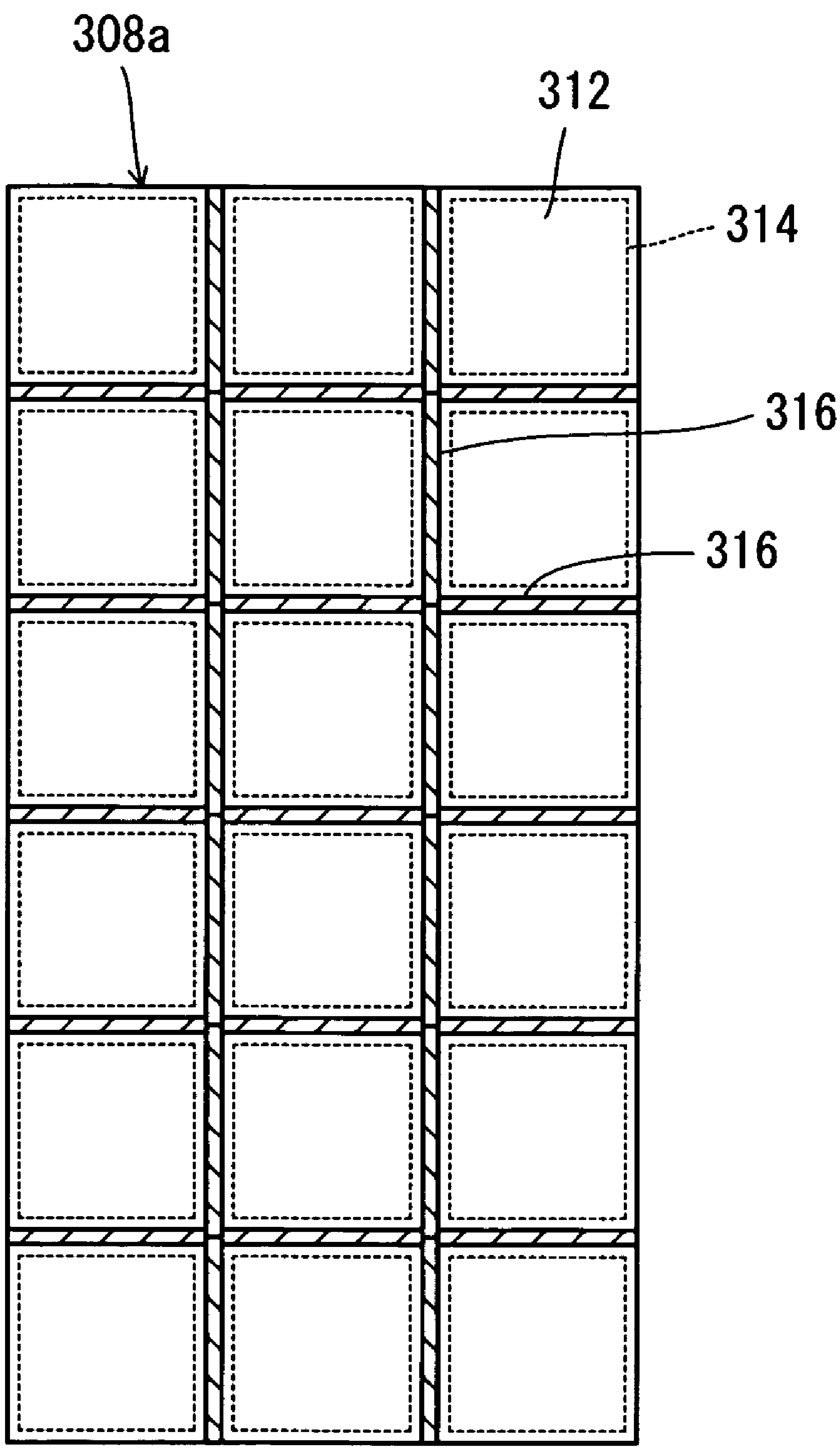
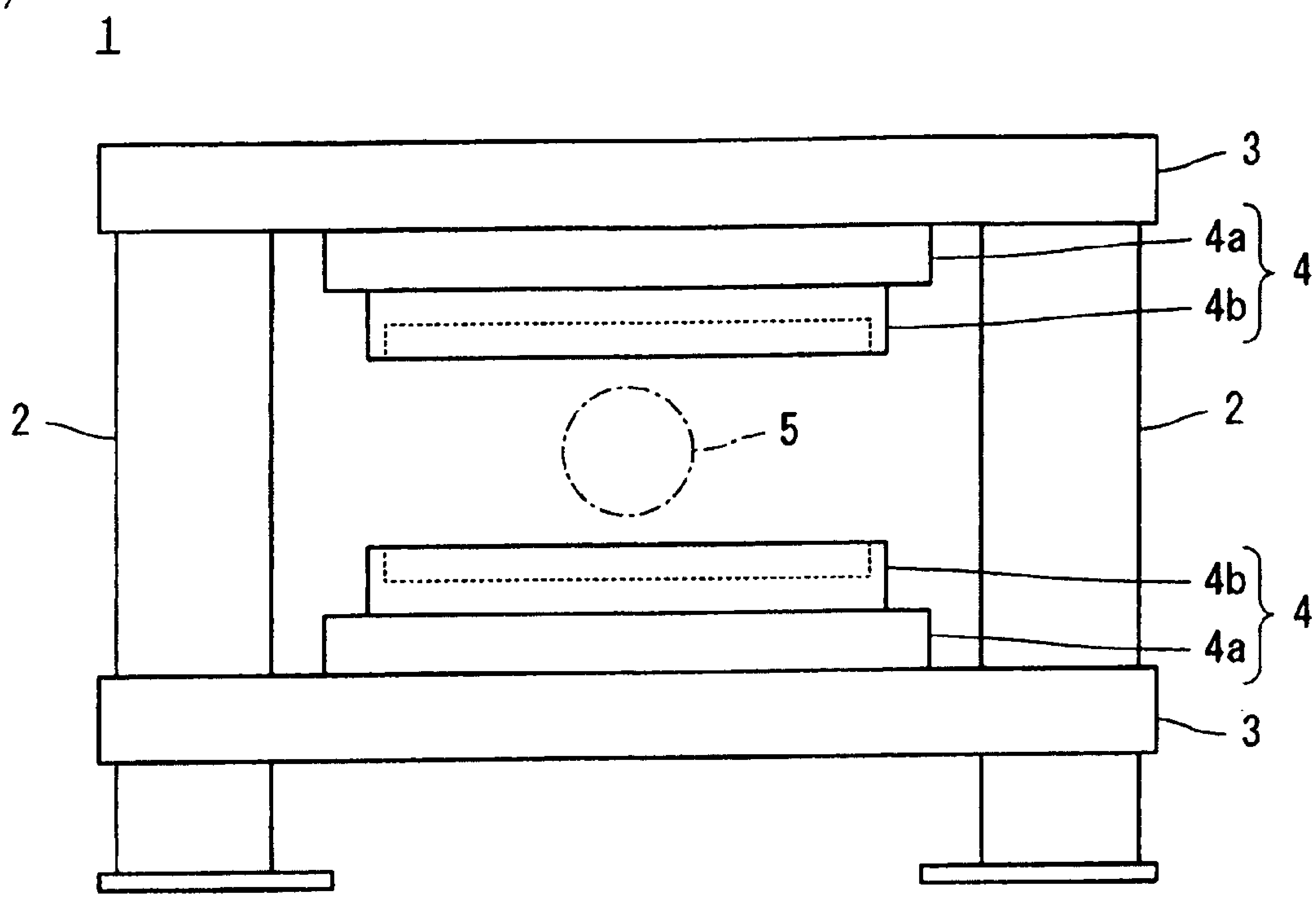
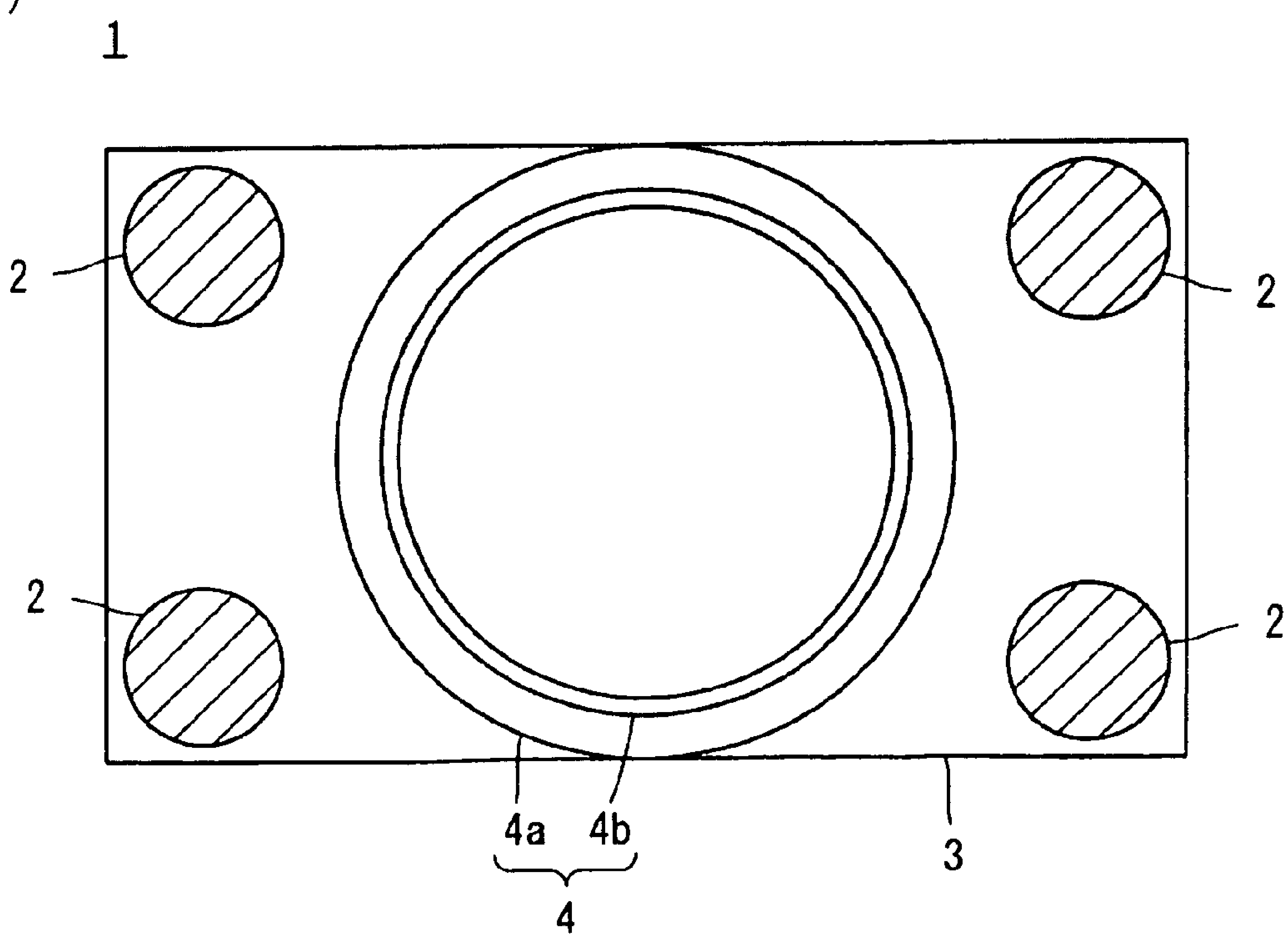


FIG. 28 PRIOR ART

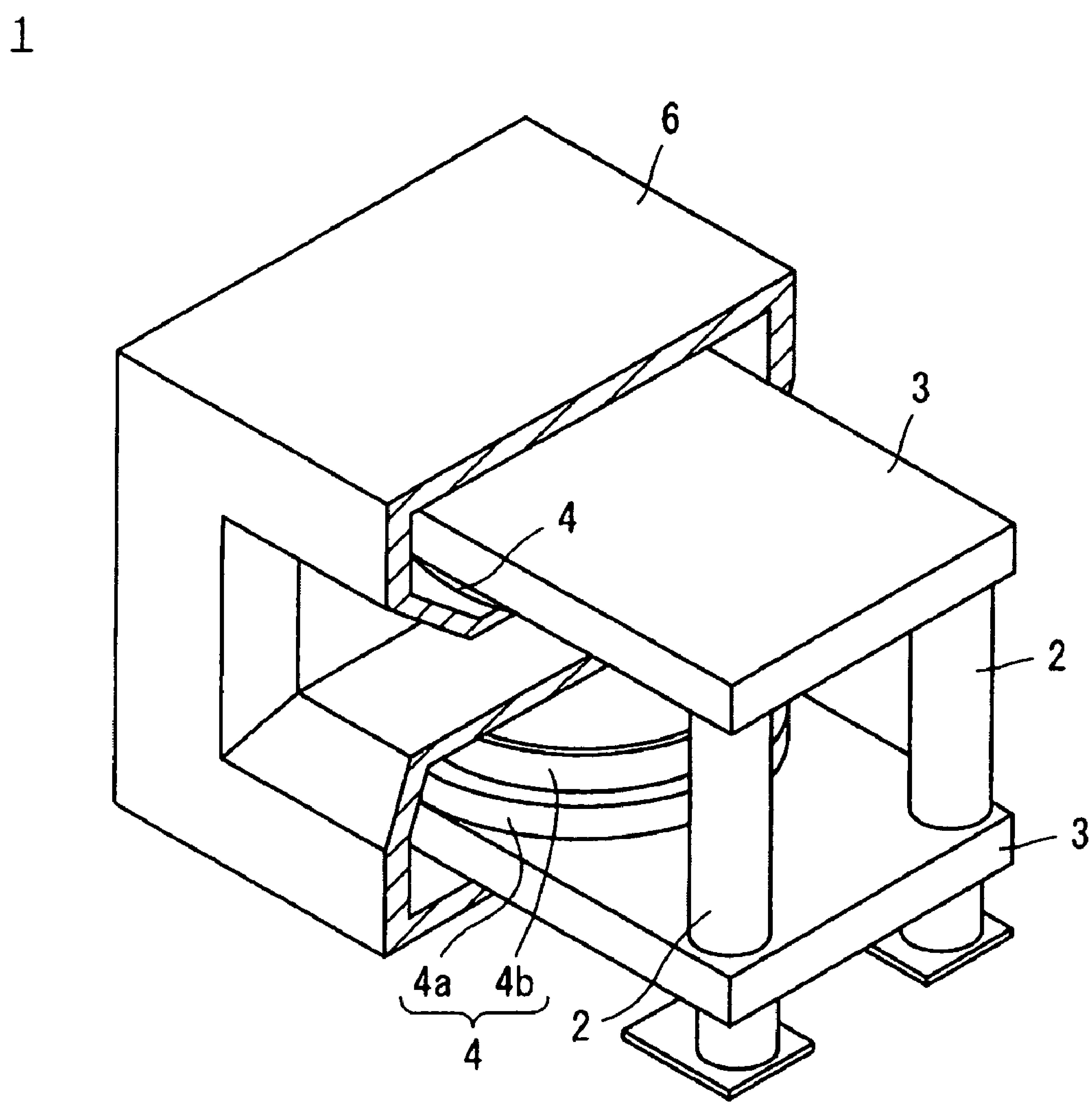
(a)



(b)



F I G. 2 9 PRIOR ART



MAGNETIC FIELD GENERATOR

TECHNICAL FIELD

The present invention relates to magnetic field generators, and more specifically to permanent magnet type magnetic field generators used in MRI (Magnetic Resonance Imaging) apparatuses, etc.

BACKGROUND ART

Conventionally, MRI apparatuses, etc. are known as an apparatus in which a specimen is placed in a magnetic field (static magnetic field) generated by a magnetic field generator and tomographic images of the specimen is obtained.

FIG. **28** shows a magnetic field generator **1** as an example of the magnetic field generator used in an MRI apparatus. The magnetic field generator **1** includes a pair of plate yokes **3** which are connected with each other by four column yokes **2**, to face each other with a space in between. The opposed surfaces of the plate yokes **3** are each provided with a magnetic pole **4**. Each magnetic pole **4** includes a permanent magnet group **4***a* fixed on the opposed surface of the plate yoke **3** and a pole piece **4***b* fixed on an opposed surface of the permanent magnet group **4***a*. The permanent magnet group **4***a* is made of a plurality of unillustrated permanent magnets. Using the permanent magnet group **4***a* in this way as the source of magnetic field generation enables to reduce running cost as compared to cases in which the magnetic field is generated by supplying electric power to electric magnets. It is also possible to reduce the size of the apparatus since there is no need for an electric power supply apparatus, etc. for driving the electric magnets.

In order to obtain clear tomographic images, the magnetic field generator **1** must be able to generate, within a magnetic field space **5** in its space, a magnetic field which has a uniformity accuracy within 1×10^{-4} (within 100 PPM) in a range of 0.02 T through 3.0 T. However, the permanent magnet group **4***a* recently is often made of Nd—Fe—B sintered magnets, which has a residual magnetic flux density temperature coefficient of −0.1%/° C. approx: Magnetic characteristics change with temperature change, so it is difficult to create a uniform magnetic field of a desired intensity. In an attempt to overcome this problem, there is prevailed a technique as shown in FIG. **29**, of covering the four column yokes **2** and the pair of plate yokes **3** where the magnetic poles **4** are provided, with a heat insulation member **6** thereby reducing the temperature change caused by changes in ambient temperature in each element (particularly the permanent magnet group **4***a*) of the magnetic field generator **1**.

Also, there is prevailed a technique of employing a heater in addition to the heat insulation member **6** to maintain the permanent magnet group **4***a* at a constant temperature. As an example, Patent Document 1 for example discloses a technique of providing a surface heater on an inner surface of the heat insulation member **6** and moving the warmed air in the heat insulation member **6** by a fan. Also, Patent Document 2 discloses a technique of providing a surface heater on a surface facing away from the opposed surface in each of the pair of plate yokes **3**. Further, Patent Document 3 discloses a technique of providing a surface heater on each side surface of the plate yokes **3**. However, the technique according to Patent Document 1 poses a problem of complication in apparatuses related to temperature control since the air must be forced to move by the fan. In addition, use of air as a heat transfer medium poses another problem that the heat generated by the surface heater is not transferred efficiently to the permanent magnet group **4***a*. The techniques according to Patent Documents 2 and 3 also have the problem of inefficient transfer of heat generated by the surface heater, to the permanent magnet group **4***a* because the heat diffuses from a surface of the surface heater facing away from the surface that makes contact with the plate yoke **3**.

In an attempt to solve these kinds of problems, Patent Document 4 discloses a technique of providing a heater inside the permanent magnet group **4***a* or the plate yokes **3**, etc. The technique according to Patent Document 4 enables to reduce diffusion of heat from the heater to outside.

Patent Document 1: JP-A 63-43649

Patent Document 2: JP-A 63-278310

Patent Document 3: JP-A 8-266506

Patent Document 4: WO 99/65392

DISCLOSURE OF THE INVENTION

Problems to be Solved by the Invention

A problem, however, according to the technique in Patent Document 4 is that heat does not reach easily to places far from the heater, leading to poor temperature following ability and temperature controllability of the elements of the magnetic field generator which are disposed far from the heater with respect to the heat generated by the heater. As another problem, the amount of heat delivered to the elements of the magnetic field generator varies widely depending on the distance from the heater, leading to uneven heating among the elements of the magnetic field generator and nonuniform temperature distribution. Generally, carbon steel and cast iron used as the column yokes **2** and the plate yokes **3** have a thermal conductivity of 75 W/m·K approx. On the contrary, Nd—Fe—B sintered magnets have a thermal conductivity of 9 W/m·K approx, i.e. lower than the thermal conductivity of the column yokes **2** and of the plate yokes **3**. Further, in the permanent magnet group **4***a*, mutually adjacent permanent magnets are bonded to each other by an adhesive which has a low thermal conductivity. Thus, these problems are likely to affect the permanent magnet group **4***a* in particular, and there has been a risk of not being able to generate a uniform magnetic field of a desired intensity.

If many heaters are used to improve temperature following ability and temperature controllability or to decrease nonuniform temperature distribution, the apparatus will become complicated, power consumption for heater operation will be increased, and running cost will be increased.

Therefore, a primary object of the present invention is to provide a magnetic field generator capable of generating a uniform magnetic field of a desired intensity easily and stably without increasing running cost.

Means for Solving the Problems

According to an aspect of the present invention, there is provided a magnetic field generator which includes a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, and a pole piece provided on an end surface of the first permanent magnet group. The pole pieces are faced to each other with a space in between. The magnetic field generator further includes: heating means for supplying heat to at least the pair of magnetic poles; and a heat conducting member provided between mutually adjacent permanent magnets at least in part of the first permanent magnet group.

According to the present invention, heat generated by the heating means is conducted uniformly and quickly by heat conducting member which is provided between mutually adjacent permanent magnets in the first permanent magnet group to the adjacent permanent magnets in the first permanent magnet group. Therefore, the magnetic field generator has a superb temperature following ability and heat controllability, and it is possible to maintain the first permanent magnet group at a constant temperature easily and uniformly, and to generate a uniform magnetic field of a desired intensity stably. Further, since heat is easily conducted to the first permanent magnet group, it is possible to reduce energy necessary to drive the heating means so running cost does not increase.

According to another aspect of the present invention, there is provided a magnetic field generator which includes a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, a pole piece provided on an end surface of the first permanent magnet group, and a second permanent magnet group including a plurality of permanent magnets and provided on an outer side surface of the pole piece. The pole pieces are faced to each other with a space in between. The magnetic field generator further includes: heating means for supplying heat to at least the pair of magnetic poles; and a heat conducting member provided between mutually adjacent permanent magnets at least in part of the second permanent magnet group.

There is already known a magnetic field generator which includes a pair of pole pieces each having its outer side surface provided with a second permanent magnet group for prevention of magnetic flux leakage. In such a magnetic field generator, the second permanent magnet group which is placed closely to the space is subject to temperature change associated with ambient temperature change, as compared to the first permanent magnet group. According to the present invention, heat generated by the heating means is conducted uniformly and quickly by the heat conducting member which is provided between mutually adjacent permanent magnets in the second permanent magnet group to the adjacent permanent magnets in the second permanent magnet group. Therefore, it is possible to maintain the second permanent magnet group which is sensitive to the ambient temperature at a constant temperature easily and uniformly, and to generate a uniform magnetic field of a desired intensity stably. Further, since heat is easily conducted to the second permanent magnet group, it is possible to reduce energy necessary to drive the heating means so running cost does not increase.

According to another aspect of the present invention, there is provided a magnetic field generator which includes a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, a pole piece provided in an end surface of the first permanent magnet group, and a plurality of second permanent magnet groups each including a plurality of permanent magnets and provided on an outer side surface of the pole piece. The pole pieces are faced to each other with a space in between. The magnetic field generator further includes: heating means for supplying heat to at least the pair of magnetic poles; and a heat conducting member provided between mutually adjacent second permanent magnet groups at least in part of the second permanent magnet groups.

According to the present invention, heat generated by the heating means is conducted by the heat conducting member provided between mutually adjacent second permanent magnet groups to these mutually adjacent second permanent magnet groups uniformly and quickly. Therefore, it is possible to maintain the second permanent magnet group which is sensitive to the ambient temperature at a constant temperature easily and uniformly. Further, it is possible to reduce temperature difference between mutually adjacent second permanent magnet groups, and to generate a uniform magnetic field of a desired intensity stably. Since heat is easily conducted to the second permanent magnet group, it is possible to reduce energy necessary to drive the heating means so running cost does not increase. Further, the arrangement is simple placement of a heat conducting member between mutually adjacent second permanent magnet groups. This enables to reduce the number of parts in the magnetic field generator and to reduce the number of manufacturing steps, as compared to a case where a heat conducting member is provided between mutually adjacent permanent magnets in the second permanent magnet group.

It should be noted here that the term “heat conducting member” means a member which has a thermal conductivity higher than the thermal conductivity of at least the first permanent magnet group and the second permanent magnet group.

Preferably, the magnetic field generator includes a heat conducting member provided on at least part of a surface of the second permanent magnet group. By providing a heat conducting member also on the surface of the second permanent magnet group as described, heat generated by the heating means is conducted more uniformly and quickly to the second permanent magnet group. Therefore, it becomes possible to generate a uniform magnetic field of a desired intensity more stably.

Further preferably, heating means is buried in the heat conducting member. By burying a heating means in the heat conducting member, heat generated by the heating means is conducted to the heat conducting member without diffusing to the outside, and therefore it becomes possible to deliver heat more quickly and efficiently to the permanent magnet group. Further, since heat is conducted to the permanent magnet group more easily, it becomes possible to further reduce energy necessary to drive the heating means and to reduce running cost.

Further preferably, the magnetic field generator includes a coating material formed on at least part of the permanent magnets and having a thermal conductivity not lower than 150 W/m·K. By forming a coating material on the permanent magnets as described, heat generated by the heating means is conducted more uniformly and quickly by the coating material to the permanent magnets and thus to the permanent magnet group. Therefore, it becomes possible to generate a uniform magnetic field of a desired intensity more stably.

Further preferably, the magnetic field generator includes a temperature sensor disposed near the heating means. By disposing a temperature sensor near the heating means as described, it becomes possible to sense the heat generated by the heating means quickly and to prevent the heating means from generating an unnecessary amount of heat. In particular, when the heating means is disposed in or near a permanent magnet group, thermal demagnetization can occur in the permanent magnets if the amount of heat generated by the heating means becomes excessively large. However, this can be prevented by placing a temperature sensor near the heating means.

Further preferably, the magnetic field generator includes a heat insulation material which covers the permanent magnet group. By covering the permanent magnet group with a heat insulation material as described, temperature change in the permanent magnet group caused by changes in the ambient temperature is reduced. Therefore, it becomes possible to maintain the permanent magnet group at a constant temperature more stably. Further, since heat diffusion from the permanent magnet group to the outside becomes less, and the temperature decrease of the permanent magnet group becomes less, it becomes possible to further reduce energy necessary to drive the heating means and to reduce running cost. The heat insulation material is suitably provided by, for example, a vacuum insulation material in the form of a vacuum pack of a core material made of inorganic fiber heat insulation material such as glass wool or foamed plastic heat insulation material such as foamed polystyrene and foamed urethane into a package made of a metal film, etc. which has a good gas insulation capability.

Further preferably, the magnetic field generator includes a heat storage member which covers the permanent magnet group. In this case, the heat storage member holds the heat of the permanent magnet group, and when the temperature of the permanent magnet group decreases, heat held in the heat storage member is conducted to the permanent magnet group. Therefore, it is possible to maintain the permanent magnet group at a constant temperature more stably. Further, since the heat is conducted from the heat storage member to the permanent magnet group when the temperature of the permanent magnet group decreases, it becomes possible to further reduce energy necessary to drive the heating means and to reduce running cost. Heat storage material included in the heat storage member is suitably provided by an inorganic hydrated salt which has a large heat storage capacity and can hold heat stably.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** A schematic perspective view of an embodiment of the present invention.

FIG. **2** A schematic side view of the embodiment in FIG. **1**.

FIG. **3** An example of permanent magnet group provided on an opposed surface of a plate yoke: FIG. **3**(*a*) is a schematic plan view whereas FIG. **3**(*b*) is a schematic side view.

FIG. **4** A disposition mode of a surface heater in the permanent magnet group in FIG. **3**: FIG. **4**(*a*) is a schematic plan view whereas FIG. **4**(*b*) is a schematic side view.

FIG. **5** A schematic perspective view of a primary portion of a permanent magnet group which includes heat conducting members in which tubular heaters are buried.

FIG. **6** A primary portion of another permanent magnet group which includes a heat conducting member in which tubular heaters are buried. FIG. **6**(*a*) is a schematic perspective view of the permanent magnet group, with the tubular heaters buried into an end portion of the heat conducting member extended along a side surface of the permanent magnet. FIG. **6**(*b*) is a schematic perspective view of the permanent magnet group, with the tubular heaters buried into a thickened end portion of the heat conducting member.

FIG. **7** Another example of the permanent magnet group provided on the opposed surface of the plate yoke. FIG. **7**(*a*) is a schematic plan view whereas FIG. **7**(*b*) is a schematic side view.

FIG. **8** Another example of the permanent magnet group provided on the opposed surface of the plate yoke. FIG. **8**(*a*) is a schematic plan view whereas FIG. **8**(*b*) is a schematic side view.

FIG. **9** Another example of the permanent magnet group provided on the opposed surface of the plate yoke. FIG. **9**(*a*) is a schematic plan view whereas FIG. **9**(*b*) is a schematic side view.

FIG. **10** A perspective view of permanent magnets and heat conducting members which constitute the permanent magnet group in FIG. **8**.

FIG. **11** Shows graphs depicting an experimental condition and an experimental result. FIG. **11**(*a*) shows a time course observation of an ambient temperature, FIG. **11**(*b*) shows a time course observation of the temperature of a permanent magnet group, and FIG. **11**(*c*) shows a time course observation of a change rate in an average magnetic field intensity.

FIG. **12** A schematic side view of a magnetic field generator used in the experiment.

FIG. **13** A schematic side view of another embodiment of the present invention.

FIG. **14** Schematic perspective view of another embodiment of the present invention.

FIG. **15** A schematic side view of the embodiment in FIG. **14**.

FIG. **16** An example of permanent magnet group provided on an outer side surface of the pole piece. FIG. **16**(*a*) is a schematic plan view whereas FIG. **16**(*b*) is a schematic side view.

FIG. **17** A disposition mode of a heat conducting member covering a surface of the permanent magnet group in FIG. **16**. FIG. **17**(*a*) is a schematic plan view whereas FIG. **17**(*b*) is a schematic side view.

FIG. **18** A schematic side view of another embodiment of the present invention.

FIG. **19** A schematic side view of another embodiment of the present invention.

FIG. **20** A schematic sectional view of a vacuum insulation material and a heat storage member.

FIG. **21** A schematic perspective view of another embodiment of the present invention.

FIG. **22** A schematic side view of the embodiment in FIG. **21**.

FIG. **23** A disposition mode of heat conducting members in a plurality of permanent magnet groups provided on an outer side surface of the pole piece. FIG. **23**(*a*) is a schematic plan view whereas FIG. **23**(*b*) is a schematic side view.

FIG. **24** A schematic perspective view of heat conducting members as an example, disposed between permanent magnet groups provided on an outer side surface of the pole piece, with tubular heater buried in each heat conducting member.

FIG. **25** A disposition mode of a heat conducting member covering end surfaces of a plurality of permanent magnet groups provided on an outer side surface of the pole piece. FIG. **25**(*a*) is a schematic plan view whereas FIG. **25**(*b*) is a schematic side view.

FIG. **26** Another embodiment of the present invention. FIG. **26**(*a*) is a schematic perspective view, FIG. **26**(*b*) is a schematic sectional view, and FIG. **26**(*c*) is a schematic plan view of a primary portion.

FIG. **27** A schematic front view of the permanent magnet group in FIG. **26**.

FIG. **28** A conventional magnetic field generator. FIG. **28**(*a*) is a schematic front view whereas FIG. **28**(*b*) is a schematic plan view

FIG. **29** A schematic perspective view of a conventional magnetic field generator.

LEGEND

10, **10***a*, **10***b*, **10***c*, **10***d*, **10***e*, **10***f*, **10***g*, **200**, **300** Magnetic field generators

12*a*, **12***b*, **338***a*, **338***b* Plate yokes

14*a*, **14***b*, **62***a*, **62***b*, **202***a*, **202***b* Magnetic poles

16*a*, **16***b*, **36***a*, **36***b*, **38***a*, **38***b*, **40***a*, **40***b*, **42***a*, **42***b***44***a*, **44***b*, **46***a*, **46***b*, **64***a*, **64***b*, **66***a*, **66***b*, **102***a*, **102***b*, **204***a*, **204***b*, **302***a*, **302***b*, **304***a*, **304***b*, **306***a*, **306***b*, **308***a*, **308***b*, **310***a*, **310***b*, **322***a*, **322***b* Permanent magnet groups

18*a*, **18***b*, **330***a*, **330***b* Pole pieces

20, **20***a*, **20***b*, **68**, **70**, **206**, **314** Permanent magnets

22, **22***a*, **22***b*, **22***c*, **22***d*, **22***e*, **22***f*, **72**, **74**, **104**, **104***a*, **106**, **316**, **318**, **320**, **324**, **326**, **332** Heat conducting members

24, **336** Temperature sensors

34, **34***a*, **34***b*, **334** Tubular heaters

35, **342** Surface heaters

48*a*, **48***b*, **76***a*, **76***b*, **80***a*, **80***b* Vacuum insulation materials

56*a*, **56***b*, **90***a*, **90***b*, **92***a*, **92***b* Heat storage members

312 Coating material

BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, embodiments of the present invention will be described with reference to the drawings.

Referring to FIG. **1** and FIG. **2**, a magnetic field generator **10** according to an embodiment of the present invention is a magnetic field generator for an open type MRI apparatus, and includes a pair of plate yokes **12***a*, **12***b* opposed to each other with a space in between and a pair of magnetic poles **14***a*, **14***b*.

The magnetic pole **14***a* includes a permanent magnet group **16***a* and a pole piece **18***a*. Likewise, the magnetic pole **14***b* includes a permanent magnet group **16***b* and a pole piece **18***b*. The permanent magnet group **16***a* is fixed on a surface which is faced to the plate yoke **12***b*, of the plate yoke **12***a*. Likewise, the permanent magnet group **16***b* is fixed on a surface which is faced to the plate yoke **12***a*, of the plate yoke **12***b*. The pole piece **18***a* is fixed on a surface which is faced to the permanent magnet group **16***b*, of the permanent magnet group **16***a*. Likewise, the pole piece **18***b* is fixed on a surface which is faced to the permanent magnet group **16***a*, of the permanent magnet group **16***b*. As understood from FIG. **2**, in the pair of magnetic poles **14***a*, **14***b* as described, the pole pieces **18***a*, **18***b* are opposed to each other, with a space in between. Also, as shown in FIG. **2**, each of the permanent magnet groups **16***a*, **16***b* includes a plurality of permanent magnets **20** and a plurality of heat conducting members **22**.

As understood from FIG. **3**(*a*) and FIG. **3**(*b*), the permanent magnet group **16***a* is an integral body of a plurality of permanent magnets **20** and a plurality of heat conducting members **22**, formed substantially in a disc-like shape. In the permanent magnet group **16***a*, the heat conducting members **22** are disposed between the permanent magnets **20** which are adjacent to each other in a predetermined direction [a left-right direction in FIG. **3**(*a*) and FIG. **3**(*b*)], and extend in a predetermined direction [a top-bottom direction in FIG. **3**(*a*)], making a stripe disposition pattern in an end view.

Those permanent magnets **20** which form a circumferential edge of the permanent magnet group **16***a* have a curved outer side surface so as to give the permanent magnet group **16***a* a circular section, and a height of 50 mm approx. The other permanent magnets **20** which form the rest of the permanent magnet group **16***a* are formed as rectangular parallelepiped (substantially cubic), with both end surfaces (the upper surface and the lower surface) having four sides each measuring 50 mm approx, and a height measuring 50 mm approx. The heat conducting member **22** are platy, having a thickness of 0.35 mm approx. and a height of 100 mm approx.

As shown in FIG. **3**(*b*), the permanent magnet group **16***a* is formed by two tiers of the permanent magnets **20**, and thus has a height of 100 mm approx. In the permanent magnet group **16***a* which is fixed on the plate yoke **12***a*, each permanent magnet **20** and each heat conducting member **22** which face the opposed surface of the plate yoke **12***a* make contact with the opposed surface of the plate yoke **12***a* (See FIG. **2**). The permanent magnet group **16***b* is the same as the permanent magnet group **16***a*, and is disposed in the same manner as the permanent magnet group **16***a*, but on the opposed surface of the plate yokes **12***b*.

It should be noted here that in the present embodiment, the permanent magnet groups **16***a*, **16***b* are formed substantially in a disc-like shape (so they have a circular section); however, the shape of the permanent magnet groups **16***a*, **16***b* is discretional. Note further, that FIG. **3**(*a*) and FIG. **3**(*b*) show the heat conducting member **22** much thicker than the actual for easier understanding.

The permanent magnets **20** used in the permanent magnet groups **16***a*, **16***b* are provided by a high saturation magnetic flux density type Nd—Fe—B sintered magnet for example. The permanent magnets **20** have a thermal conductivity of 9 W/m·K approx. The permanent magnets **20** as described are built with a plurality of unillustrated individual magnets, which are bonded together with adhesive, etc. The heat conducting members **22** are made of aluminum for example. The heat conducting members **22** have a thermal conductivity not lower than 150 W/m·K.

As shown in FIG. **3**(*a*), the permanent magnet group **16***a* is provided with temperature sensors **24** on its side surface along its diameter as in an end view. As shown in FIG. **3**(*b*) in a side view, the temperature sensors **24** are attached to the side surface of the permanent magnet group **16***a*, one on a permanent magnet **20** in the lower tier, and the other on a permanent magnet **20** right above in the upper tier. The permanent magnet group **16***b* also is provided with temperature sensors **24** in the same manner as described. The temperature sensors **24** are controlled by an unillustrated controller, and temperatures measured by the temperature sensors **24** (measured temperatures), i.e. the temperatures of the permanent magnet groups **16***a*, **16***b*, are obtained by the controller.

It should be noted here that locations and the number of the temperature sensors **24** are discretional. Also, the temperature sensors **24** may be provided by any known temperature sensor which utilizes a thermocouple, resistance thermometer bulb, thermistor, etc.

Returning to FIG. **1** and FIG. **2**, the pole piece **18***a* includes a disc-like base plate disposed on the opposed surface of the permanent magnet group **16***a*. The base plate is made of iron for example. The base plate has a main surface formed with a silica steel sheet to prevent generation of eddy current. The silica steel sheet is made of a plurality of block-like layers, and is fixed on the base plate. Further, the base plate has a circumferential edge region formed with an annular projection **26** of iron for example, in order to increase magnetic intensity as well as to improve magnetic field uniformity. In an inner recess on the pole pieces **18***a* formed by the annular projection **26**, an unillustrated gradient coil is disposed. The pole piece **18***b* is the same as the pole piece **18***a*.

The plate yokes **12***a*, **12***b* are magnetically connected with each other by a support yoke **28** which connects rear end portions of the plate yokes **12***a*, **12***b*. The plate yokes **12***a*, **12***b* are connected with the support yoke **28** substantially at 90 degrees so as to make a generally U-shaped structure in a side view (See FIG. **2**). In addition, the plate yoke **12***a* has its lower surface (the surface away from the opposed surface) provided with four legs **30**.

The magnetic field generator **10** must be able to generate, in its magnetic field space F between the pair of pole pieces **18***a*, **18***b* (See FIG. **2**), a magnetic field with uniformity accuracy within 1×10^{-4} (within 100 PPM) in a range of 0.02 T through 3.0 T. Magnetic characteristics of the permanent magnet groups **16***a*, **16***b* change as the temperature of the permanent magnet groups **16***a*, **16***b* changes with the room temperature (ambient temperature) in the room where the magnetic field generator **10** is placed. In order to reduce the temperature change of the permanent magnet groups **16**a, **16**b, a heat insulation member **32** is provided (See FIG. **1**). The heat insulation member **32** covers the pair of plate yokes **12**a, **12**b provided with the magnetic poles **14**a, **14**b respectively, the support yoke **28** and the four legs **30**.

The heat insulation member **32** is made, for example, of an inorganic fiber heat insulation material such as glass wool, or a foamed plastic heat insulation material such as foamed polystyrene and foamed urethane. In order to reduce temperature change more effectively in the permanent magnet groups **16**a, **16**b, the heat insulation member **32** may be made of a vacuum insulation material which has a smaller thermal conductivity than any of the above heat insulation material used alone. Obviously, an envelope provided by the heat insulation member **32** will reduce temperature change not only of the permanent magnet groups **16**a, **16**b but also of each element in the magnetic field generator **10**.

In order to maintain the permanent magnet groups **16**a, **16**b at a constant temperature even when the ambient temperature changes, the magnetic field generator **10** further includes tubular heaters **34** incorporated (buried) in the plate yokes **12**a, **12**b. The tubular heaters **34** which serve as heating means are placed in insertion holes provided in the side surfaces of the plate yokes **12**a, **12**b. When placing the tubular heaters **34** in the respective insertion holes provided in the plate yokes **12**a, **12**b, spaces around the heaters are completely filled with heat resistant filler for example, for maximum heat conduction.

The tubular heater **34** can be built with a metal pipe of aluminum or stainless steel for example, a heating element placed therein, and insulation material such as MgO (magnesium oxide) filled in the metal pipe. The tubular heater **34** generates heat from electric power supplied via lead wires from an unillustrated temperature adjuster operated by the controller. Operating time and the amount of heat generation of the tubular heaters **34** are controlled based on a result of comparison between measured temperatures obtained from the temperature sensors **24** and a predetermined target temperature, through adjustment by the controller on the amount of power supply from the temperature adjuster. Specifically, the controller gives the temperature adjuster an instruction to start power supply to the tubular heaters **34** or an instruction to increase power supply to the tubular heaters **34**, in response to decrease in the measured temperatures, so as to raise the measured temperatures to the target temperature. Heat generated by the tubular heaters **34** is conducted via the plate yokes **12**a, **12**b to each of the permanent magnets **20** of the permanent magnet groups **16**a, **16**b and to each of the heat conducting members **22**.

The term "target temperature" is a target value of temperature to be measured by the temperature sensor **24**, i.e. a temperature at which the permanent magnet groups **16**a, **16**b are to be maintained. Heat generated by the tubular heaters **34** is conducted not only to the permanent magnet groups **16**a, **16**b but also to each element of the magnetic field generator **10**, obviously.

According to the magnetic field generator **10** as the above, heat which is conducted from the tubular heaters **34** via the plate yokes **12**a, **12**b to the permanent magnet groups **16**a, **16**b is conducted uniformly and quickly through the heat conducting members **22** which have a greater thermal conductivity than the permanent magnets **20**, to adjacent permanent magnets **20** in the permanent magnet groups **16**a, **16**b. Therefore, it is possible to maintain the permanent magnet groups **16**a, **16**b at a constant temperature easily and uniformly, and to generate a uniform magnetic field of a desired intensity stably in the magnetic field space F.

Further, since heat is easily conducted to each of the permanent magnets **20** in the permanent magnet groups **16**a, **16**b, it is possible to reduce electric power to be supplied to the tubular heaters **34** and to reduce running cost.

The heat conducting members **22** should preferably be nonmagnetic members in order not to deteriorate uniformity and stability of the magnetic field intensity in the magnetic field space F. The material for the heat conducting members **22** is not limited to aluminum which was mentioned earlier, but the material should preferably have a thermal conductivity not lower than 150 W/m·K. An example of alternative materials to aluminum usable for the heat conducting members **22** is copper. As another example, the heat conducting member **22** may be made of a highly thermal conductive carbon fiber which has a thermal conductivity of 350 W/m·K approx, i.e. higher than aluminum and copper, and is capable of achieving more efficient heat conduction to each of the permanent magnets **20**.

The thickness of the heat conducting member **22** is preferably not greater than 10 mm although there is no specific limitation. When the thickness of the heat conducting member **22** is not greater than 10 mm, the distance between the permanent magnets **20** is not excessively large, and the magnetic field intensity in the magnetic field space F is not decreased very much. Uniformity in the magnetic field intensity is not decreased very much, either.

Further, instead of or in addition to the tubular heaters **34**, any heaters may be used in any place or in any number. For example, the tubular heaters **34** may be buried in the support yoke **28**, or as shown in FIG. **4**(a) and FIG. **4**(b), surface heaters **35** may be provided on side surfaces of the permanent magnet groups **16**a, **16**b. As shown in FIG. **4**(a), the surface heaters **35** should preferably make contact with each heat conducting member **22**. This makes possible to conduct heat more quickly to each of the permanent magnets **20** and thus to the permanent magnet groups **16**a, **16**b.

Another variation is shown in FIG. **5**, where permanent magnet groups **36**a, **36**b are formed of permanent magnets **20**a and heat conducting members **22**a including an end provided with two insertion holes **23**. In each insertion hole **23** there is provided a tubular heater **34**a without any space remaining inside the hole. Burying the tubular heaters **34**a in the heat conducting members **22**a as described enables to deliver heat which is generated by the tubular heaters **34**a efficiently to the permanent magnet groups **36**a, **36** without allowing the heat to diffuse to the outside as compared to the use of surface heater **35**. Additional insertion holes may be made on the end of the heat conducting members **22**a, and tubular temperature sensors may be disposed in these insertion holes. It should be noted here that FIG. **5** show part of the permanent magnet groups **36**a, **36**b.

Generally, the outer diameter of tubular heaters is 5 mm approx. at the smallest, so it becomes difficult to bury the tubular heaters **34**a if the heat conducting member is thin. To avoid this, as shown in FIG. **6**(a), permanent magnet groups **38**a, **38**b may be formed of the permanent magnets **20** and heat conducting members **22**b which have end portions that follow the side surface of the permanent magnets **20**. In this case, tubular heaters **34**a are placed in respective insertion holes **23**a provided in the end portions of the heat conducting members **22**b. Likewise, as shown in FIG. **6**(b), permanent magnet groups **40**a, **40**b may be formed of heat conducting members **22**c which have thickened end portions, and permanent magnets **20**b have a cutout to be fitted by the end portion of the heat conducting member **22**c. In this case, the tubular heaters **34***a* are placed in insertion holes **23***b* provided in the thickened end portions of the heat conducting members **22***c*. It should be noted here that FIG. **6**(*a*) and FIG. **6**(*b*) show part of the permanent magnet groups **38***a*, **38***b*, **40***a*, **40***b*.

Further, the disposition mode of heat conducting members is not limited to the one used in the above-described permanent magnet groups **16***a*, **16***b*. FIG. **7** through FIG. **9** show other disposition mode examples of the heat conducting members in the permanent magnet group.

In FIG. **7**(*a*) and FIG. **7**(*b*), permanent magnet groups **42***a*, **42***b* are provided, in addition to heat conducting members **22**, with disc-like heat conducting members **22***d* covering all end surfaces (upper surfaces and lower surfaces) of permanent magnets **20** and of heat conducting members **22**. With this arrangement, heat is conducted to each of the permanent magnets **20** and heat conducting members **22** via the heat conducting members **22***d* which make contact with the opposed surfaces of the plate yokes **12***a*, **12***b*, allowing the heat to move further to the heat conducting members **22***d* disposed on the opposed-surface side of the permanent magnet groups **42***a*, **42***b*. Therefore, it is possible to deliver heat to each permanent magnet **20** more uniformly and more quickly than in the case where only one type of heat conducting member **22** is used.

FIG. **8**(*a*) and FIG. **8**(*b*) show permanent magnet groups **44***a*, **44***b*. As understood also from FIG. **10**, a heat conducting member **22***e* is disposed between those permanent magnets **20** which are mutually adjacent in a top-bottom direction, a left-right direction or an up-down direction. As in an end view, the heat conducting members **22***e* make a grid-like disposition pattern extending in the top-bottom and the left-right directions. As understood from FIG. **8**(*a*) and FIG. **8**(*b*), each heat conducting member **22***e* has its end making contact with another. According to the permanent magnet groups **44***a*, **44***b* as described, the heat conducting members **22***e* which is provided between all mutually adjacent permanent magnets **20** enables to deliver heat more uniformly and more quickly to each of the permanent magnets **20**.

FIG. **9**(*a*) and FIG. **9**(*b*) show permanent magnet groups **46***a*, **46***b*. A heat conducting member **22***f* is disposed between selected permanent magnets **20** of those which are mutually adjacent in a top-bottom direction or in a left-right direction as in an end view. These heat conducting members **22***f* are disposed in a cross-like pattern as in an end view. Disposing the heat conducting members **22***f* in a cross-like pattern in an end view enables to deliver heat uniformly and quickly to center regions of the permanent magnet groups **46***a*, **46***b* which have major influence on the uniformity and stability of the magnetic field intensity in the magnetic field space F.

Next, reference will be made to FIG. **11** to describe an experiment example in which magnetic field generators **10** and **200** (See FIG. **12**) are used, and measurements were made to the temperature of the permanent magnet groups and the magnetic field intensity while decreasing the ambient temperature.

The magnetic field generators **10** and **200** differ from each other only in that the heat conducting members are not provided between mutually adjacent permanent magnets **206** in permanent magnet groups **204***a*, **204***b* which constitute a pair of magnetic poles **202***a*, **202***b* in the magnetic field generator **200**.

As shown in FIG. **11**(*a*), the ambient temperature was decreased from 25° C. to 20° C. in the experiment, and measurements were made for the temperature of the permanent magnet group **16***a* in the magnetic field generator **10**, and the temperature of the permanent magnet group **204***a* in the magnetic field generator **200**. Further, magnetic field intensity was measured at a plurality of points in the magnetic field space F of the magnetic field generator **10** and at a plurality of points in the magnetic field space F of the magnetic field generator **200**. In the experiment, the target temperature was set to 30° C. for each of the magnetic field generators **10** and **200**.

FIG. **11** (*b*) shows temperature change in the permanent magnet groups **16***a*, **204***a*. A**1** shows a time course observation of the measured temperature detected by the temperature sensor **24** which is provided on a permanent magnet **20** in the lower tier of the permanent magnet group **16***a* in FIG. **2**. B**1** shows a time course observation of the measured temperature detected by the temperature sensor **24** which is provided on a permanent magnet **20** in the upper tier of the permanent magnet group **16***a* in FIG. **2**. Likewise, A**2** shows a time course observation of the measured temperature detected by the temperature sensor **24** which is provided on a permanent magnet **206** in the lower tier of the permanent magnet group **204***a* in FIG. **12**, whereas B**2** shows a time course observation of the measured temperature detected by the temperature sensor **24** which is provided on a permanent magnet **206** in the upper tier of the permanent magnet group **204***a* in FIG. **12**.

Comparison between A**1**, B**1** and A**2**, B**2** reveals: All measured temperature showed decrease as the ambient temperature decreased. However, the temperature decrease was smaller in A**1**, B**1** and the temperature came back to the target temperature more quickly than in A**2**, B**2**. Difference in temperature decrease, and difference in the length of time necessary to come back to the target temperature were particularly large between B**1** and B**2**.

This indicates that in the magnetic field generator **10**, each heat conducting member **22** was able to deliver heat quickly from the plate yoke **12***a* to each permanent magnet **20**, achieving quicker follow up than in the magnetic field generator **200**, when the amount of heat from the tubular heaters **34** was increased. Particularly in the magnetic field generator **200**, heat was not delivered as quickly to permanent magnets **206** in the upper tier which did not have contact with the plate yoke **12***a*, of the permanent magnet group **204***a*. On the contrary, in the magnetic field generator **10**, heat was delivered quickly by the heat conducting members **22** to the permanent magnets **20** in the upper tier of the permanent magnet group **16***a*.

In A**2**, B**2**, the measured temperature approached the target temperature with time, but staggered up and down (indicated by Arrows X**1**, X**2**) around the target temperature before the temperature stabilized at the target temperature, and it took a long time before the temperature stabilized at the target temperature. This is a result of poor heat delivery to the permanent magnet group **204***a*, which lead to a time lag between increase in the amount of heat generated by tubular heaters **34** and temperature increase in the permanent magnet group **204***a*. As a result, the permanent magnet group **204***a* was supplied with a more amount of heat than necessary to come back to the target temperature. Such a phenomenon did not take place in A**1**, B**1**.

It should be noted here that the same temperature change pattern as in FIG. **11**(*b*) should be observed in the permanent magnet group **16***b* and the permanent magnet group **204***b*, obviously.

Next, FIG. **11**(*c*) shows a time course observation on a rate of change in an average magnetic field intensity. C**1** represents a time course observation of a rate of change in an average magnetic field intensity in the magnetic field space F of the magnetic field generator **10**, whereas C**2** represents a time course observation of a rate of change in an average magnetic field intensity in the magnetic field space F of the magnetic field generator **200**. The term "average magnetic field intensity" means an average of magnetic field intensity measurements at a plurality of points in the magnetic field space F.

Comparison between C**1** and C**2** reveals: A maximum value of the rate of change in the average magnetic field intensity was 300 PPM in C**1**, whereas in C**2**, a maximum value of the rate of change in the average magnetic field intensity was 500 PPM. In C**2**, it took time for the permanent magnet groups **204***a*, **204***b* of the magnetic field generator **200** to stabilize at the target temperature [See also areas indicated by Arrows X**1**, X**2** in FIG. **11**(*b*)]. Because of this, the rate of change in the average magnetic field intensity staggered up and down (indicated by Arrow X**3**) around 0 PPM before it stabilized at 0 PPM, and it took a long time before stabilizing at 0 PPM. Such a phenomenon did not take place in C**1**.

Thus, it is understood that in the magnetic field generator **10**, temperature change is small in the permanent magnet groups **16***a*, **16***b* and it is possible to come back to the target temperature in a short time; therefore, it is possible to generate a magnetic field of a desired intensity more stably in the magnetic field space F than the magnetic field generator **200**.

Next, description will cover a magnetic field generator **10***a* as another embodiment of the present invention, with reference to FIG. **13**.

The magnetic field generator **10***a* is the magnetic field generator **10** which is provided with vacuum insulation materials **48***a*, **48***b* covering the permanent magnet groups **16***a*, **16***b* respectively, and covers **50***a*, **50***b* covering the vacuum insulation materials **48***a*, **48***b* respectively. All the other aspects are the same with the magnetic field generator **10** and description will not be repeated for the same parts.

The vacuum insulation material **48***a* is formed annularly, to have an inner diameter essentially the same as the outer diameter of the permanent magnet group **16***a*, and is disposed on the opposed surface of the plate yoke **12***a* to cover the side surface of the permanent magnet group **16***a*. The vacuum insulation material **48***b* is essentially the same as the vacuum insulation material **48***a*, and is disposed in the same manner as the vacuum insulation material **48***a*, on the opposed surface of the plate yoke **12***b* to cover the side surface of the permanent magnet group **16***b*.

The cover **50***a* is fixed on the opposed surface of the plate yoke **12***a*, and covers the outer circumference of the vacuum insulation material **48***a*, thereby limiting movements of the vacuum insulation material **48***a* which makes contact with the side surface of the permanent magnet group **16***a*. Likewise, the cover **50***b* is fixed on the opposed surface of the plate yoke **12***b* so as to limit movements of the vacuum insulation material **48***b*.

Each of the vacuum insulation materials **48***a*, **48***b* includes porous core material **52** made of glass wool as an example of inorganic fiber heat insulation material, and a package **54** made of a laminated aluminum film for holding the core material **52**. Inside of the package **54** is vacuum, and the vacuum insulation materials **48***a*, **48***b* are provided as vacuum packs of the core material **52** in the package **54**. The vacuum insulation materials **48***a*, **48***b* as described have a thermal conductivity of 0.01 W/m·K approx. Obviously, a higher level of vacuum in the package **54** will provide a smaller thermal conductivity.

According to the magnetic field generator **10***a* as described, the vacuum insulation materials **48***a*, **48***b* cover the permanent magnet groups **16***a*, **16***b* respectively, thereby preventing heat from diffusing from the permanent magnet groups **16***a*, **16***b* to the outside, to reduce temperature change of the permanent magnet groups **16***a*, **16***b* due to ambient temperature change. Therefore, it is possible to maintain the permanent magnet groups **16***a*, **16***b* at a constant temperature more stably.

Further, since heat does not diffuse easily from the permanent magnet groups **16***a*, **16***b* to the outside and therefore the temperature of the permanent magnet groups **16***a*, **16***b* does not decrease easily, it becomes possible to reduce electric power to be supplied to the tubular heaters **34** and to reduce running cost.

The vacuum insulation materials **48***a*, **48***b* may be provided by a plurality of arcuate members.

The material for the core material **52** is not limited to glass wool; any foamed plastic heat insulation material such as foamed polystyrene and foamed urethane or any other material may be used. Likewise, the material for the package **54** is not limited to the laminated aluminum film; plastic film, etc. may be used to form the package **54**.

Next, description will cover a magnetic field generator **10***b* which is also shown in FIG. **13** as is the magnetic field generator **10***a*. The magnetic field generator **10***b* differs from the magnetic field generator **10***a* in that it uses heat storage members **56***a*, **56***b* in place of the vacuum insulation materials **48***a*, **48***b*. All the other aspects are the same with the magnetic field generator **10***a* and description will not be repeated for the same parts.

Each of the heat storage members **56***a*, **56***b* includes a heat storage material **58** and a package **60** which is formed of a synthetic resin such as polypropylene for holding the heat storage material **58**. The heat storage material **58** is preferably provided by an inorganic hydrated salt which has a high heat storage capacity and is able to hold the heat stably. Without any specific limitation to the kind of inorganic hydrated salt to be used as the heat storage material **58**, the inorganic hydrated salt should preferably be fire retardent. Examples include calcium chloride hydrates, sodium sulfate hydrates, and sodium acetate hydrates. Other examples than the inorganic hydrated salts usable as the heat storage material **58** are organic compounds such as paraffin. Regardless of the selection, the heat storage material **58** should preferably have a heat storage capacity not smaller than 100 J/g and be fire retardent.

According to the magnetic field generator **10***b* as described, the heat storage material **58** in each of the heat storage members **56***a*, **56***b* keeps the heat of the permanent magnet groups **16***a*, **16***b*. When the temperature of the permanent magnet groups **16***a*, **16***b* decreases, heat held in the heat storage material **58** is conducted to the permanent magnet groups **16***a*, **16***b*. Therefore, it is possible to maintain the permanent magnet groups **16***a*, **16***b* at a constant temperature more stably.

Further, when the temperature of the permanent magnet groups **16***a*, **16***b* decreases, heat is conducted from the heat storage material **58** to the permanent magnet groups **16***a*, **16***b*, so it is possible to reduce electric power to be supplied to the tubular heaters **34** and to reduce running cost.

Next, reference will be made to FIG. **14** and FIG. **15**, to describe a magnetic field generator **10***c* as another embodiment of the present invention.

The magnetic field generator **10***c* is the magnetic field generator **10** in which the pair of magnetic poles **14***a*, **14***b* are replaced by a pair of magnetic poles **62***a*, **62***b*. All the other aspects are the same with the magnetic field generator **10** and description will not be repeated for the same parts.

The magnetic pole **62***a* includes a permanent magnet group **64***a*, a pole piece **18***a*, and a plurality of permanent magnet groups **66***a*. Likewise, the magnetic pole **62***b* includes a permanent magnet group **64**b, a pole piece **18**b and a plurality of permanent magnet groups **66**b.

As shown in FIG. **15**, the permanent magnet group **64**a is provided by a plurality of permanent magnets **68**, and is fixed on the opposed surface of the plate yoke **12**a. Likewise, permanent magnet group **64**b is provided by a plurality of permanent magnets **68**, and is fixed on the opposed surface of the plate yoke **12**b. The pole piece **18**a is fixed on the opposed surface of the permanent magnet group **64**a. Likewise, the pole piece **18**b is fixed on the opposed surface of the permanent magnet group **64**b. The permanent magnet groups **66**a are fixed on an outer side surface of the pole piece **18**a to prevent magnetic flux leakage. Likewise, the permanent magnet groups **66**b are fixed on an outer side surface of the pole piece **18**b to prevent magnetic flux leakage.

It should be noted here that in the present embodiment, the permanent magnet groups **64**a, **64**b serve as the first permanent magnet groups whereas the permanent magnet groups **66**a, **66**b serve as the second permanent magnet groups.

As understood from FIG. **16**(a) and FIG. **16**(b), the permanent magnet group **66**a is an integral body of a plurality of permanent magnets **70** and a plurality of heat conducting members **72** formed substantially in a rectangular parallelepiped which has a side surface shaped to fit the outer side surface of the pole piece **18**a. As shown in FIG. **16**(a) and FIG. **16**(b), in the permanent magnet group **66**a, the permanent magnets **70** are placed in a front-rear direction [top-bottom direction in FIG. **16**(a)] in two rows, as well as in two tiers. Further, in the permanent magnet group **66**a, the heat conducting members **72** are disposed between the permanent magnets **70** which are adjacent to each other in a predetermined direction [a left-right direction in FIG. **16**(a) and FIG. **16**(b)], and extends in a predetermined direction [a top-bottom direction in FIG. **16**(a)], making a stripe disposition pattern in an end view. In the permanent magnet group **66**a which is fixed on the pole piece **18**a, each of the permanent magnets **70** and heat conducting members **72** facing the pole piece **18**a makes contact with the pole piece **18**a. The permanent magnet group **66**b is essentially the same as the permanent magnet group **66**a, and is provided on the pole piece **18**b in the same manner as is the permanent magnet group **66**a.

The permanent magnets **70** used in the permanent magnet groups **66**a, **66**b are provided by a high coercivity type Nd—Fe—B magnet. The permanent magnets **70** have a thermal conductivity of 9 W/m·K approx. The permanent magnets **70** as described are built with a plurality of unillustrated individual magnets, which are bonded together with adhesive, etc. The heat conducting members **22** are made of aluminum for example, and have a thickness of 0.35 mm. The heat conducting members **72** have a thermal conductivity not lower than 150 W/m·K. It should be noted here that FIG. **16**(a) and FIG. **16**(b) show the heat conducting member **22** thicker than the actual for easier understanding.

Returning to FIG. **14** and FIG. **15**, heat which is generated by the tubular heaters **34** is conducted to the plate yokes **12**a, **12**b, the permanent magnet group **64**a, **64**b and then the pole pieces **18**a, **18**b in this sequence, and is conducted to each of the permanent magnets **70** and heat conducting members **72** in the permanent magnet groups **66**a, **66**b.

According to the magnetic field generator **10**c as the above, heat which is conducted from the tubular heaters **34** via the pole pieces **18**a, **18**b to the permanent magnet groups **66**a, **66**b is conducted to mutually adjacent permanent magnets **70** uniformly and quickly through the heat conducting members **72** which have a greater thermal conductivity than the permanent magnets **70**. Therefore, even if the permanent magnet groups **66**a, **66**b are close to the space and are sensitive to ambient temperature, it is possible to maintain a constant temperature easily and uniformly, and to generate a uniform magnetic field of a desired intensity stably in the magnetic field space F.

Further, since heat is easily conducted to each of the permanent magnets **70** in the permanent magnet groups **66**a, **66**b, it is possible to reduce electric power to be supplied to the tubular heaters **34** and to reduce running cost.

The heat conducting members **72** should preferably be a nonmagnetic member in order not to decrease uniformity and stability of the magnetic field intensity in the magnetic field space F. The material for the heat conducting member **72** is not limited to aluminum which was mentioned earlier, and the heat conducting member **72** may be provided by copper, or a highly thermal conductive carbon fiber, etc.

Further, the disposition mode of the heat conducting members is not limited to the one used in the permanent magnet groups **66**a, **66**b: For example, the heat conducting members may be placed between all of the permanent magnets **70** which are mutually adjacent in the front-rear direction, the left-right direction or the up-down direction.

Further, the arrangement used for the permanent magnet group **36**a, **36**b (See FIG. **5**) may also be used; specifically, the permanent magnet groups **66**a, **66**b may use a heat conducting member formed with insertion holes and tubular heaters may be placed in these insertion holes. Burying the tubular heaters in the heat conducting members enables to deliver heat generated by the tubular heaters efficiently to each of the permanent magnets **70** in the permanent magnet groups **66**a, **66**b without allowing the heat to diffuse to the outside.

Also, as shown in FIG. **17**(a) and FIG. **17**(b), a plurality of platy heat conducting members **74** may cover the surfaces of permanent magnet groups **66**a, **66**b. This enables to deliver heat more uniformly and quickly to each of the permanent magnets **70**, and therefore to maintain the permanent magnet groups **66**a, **66**b, which is sensitive to ambient temperature, more stably and uniformly at a constant temperature, and thereby to generate a uniform magnetic field of a desired intensity in the magnetic field space F more stably. Also, heat conducting members provided with insertion holes may be used to cover surfaces of the permanent magnet groups **66**a, **66**b, with the insertion holes of the heat conducting members provided with tubular heaters.

Further, the permanent magnet groups **64**a, **64**b may be replaced by the permanent magnet groups **16**a, **16**b described earlier, as exemplified in FIG. **18** by a magnetic field generator **10**d. This enables to maintain the permanent magnet groups **16**a, **16**b, **66**a and **66**b at a constant temperature easily and uniformly and thus to generate a uniform magnetic field of a desired intensity in the magnetic field space F more stably. Also, heat is efficiently conducted through the heat conducting members **22** to the permanent magnet groups **16**a, **16**b, then to the pole pieces **18**a, **18**b and to the permanent magnet groups **66**a, **66**b quickly, so it is possible to reduce electric power to be supplied to the tubular heaters **34** and to reduce running cost.

Next, reference will be made to FIG. **19** to describe a magnetic field generator **10**e as another embodiment of the present invention.

The magnetic field generator **10**e is the magnetic field generator **10**d provided with vacuum insulation materials **76**a, **76**b which cover the permanent magnet groups **16**a, **16**b respectively, covers **78**a, **78**b which cover the vacuum insulation materials **76**a, **76**b respectively, and vacuum insulation materials **80**a, **80**b which cover the permanent magnet groups

66*a*, 66*b* respectively. All the other aspects are the same with the magnetic field generator 10*d* and description will not be repeated for the same parts.

The vacuum insulation material 76*a* is formed annularly, to have an inner diameter essentially the same as the outer diameter of the permanent magnet group 16*a*, and is disposed on the opposed surface of the plate yoke 12*a* to cover the side surface of the permanent magnet group 16*a*. The vacuum insulation material 76*b* is essentially the same as the vacuum insulation material 76*a*, and is disposed in the same manner as the vacuum insulation material 76*a*, on the opposed surface of the plate yoke 12*b*.

The cover 78*a*, which is fixed on the opposed surface of the plate yoke 12*a*, and covers the outer circumference of the vacuum insulation material 76*a*, thereby limiting movements of the vacuum insulation material 76*a* which makes contact with the side surface of the permanent magnet group 16*a*. Likewise, the cover 78*b* is fixed on the opposed surface of the plate yoke 12*b* so as to limit movements of the vacuum insulation material 76*b*.

The vacuum insulation material 80*a* is formed to have essentially a U-shaped section, and is disposed to cover the outer surfaces of the permanent magnet groups 66*a*. The vacuum insulation material 80*b* is essentially the same as the vacuum insulation material 80*a*, and is disposed in the same manner as the vacuum insulation material 80*a*, to cover the outer faces of the permanent magnet groups 66*b*.

As shown in FIG. 20, the vacuum insulation material 76*a* includes a core material 82 and a package 84 which holds the core material 82, and is provided as a vacuum pack of the core material 82 in the package 84. The vacuum insulation material 76*b* is the same. The vacuum insulation material 80*a* includes a core material 86 and a package 88 which holds the core material 86, and is provided as a vacuum pack of the core material 86 in the package 88. The vacuum insulation material 80*b* is the same. The vacuum insulation materials 76*a*, 76*b*, 80*a* and 80*b* each have a thermal conductivity of 0.01 W/m·K approx. The core materials 82, 86 are made of the same material as used in the core material 52 for the vacuum insulation materials 48*a*, 48*b* described earlier whereas the packages 84, 88 are made of the same material as used in the package 54 for the vacuum insulation materials 48*a*, 48*b* described earlier.

According to the magnetic field generator 10*e* as described, the vacuum insulation materials 76*a*, 76*b*, 80*a* and 80*b* cover the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* respectively, thereby prevent heat from diffusing from the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* to the outside, reduce temperature change of the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* due to ambient temperature change. Therefore, it is possible to maintain the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* at a constant temperature more stably.

Further, heat diffusion from the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* to the outside is decreased and temperature decrease in the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* is less; therefore it is possible to reduce electric power to be supplied to the tubular heaters 34 and to reduce running cost.

It should be noted here that the magnetic field generator 10*e* may be provided with the vacuum insulation materials 76*a*, 76*b* alone or with the vacuum insulation materials 80*a*, 80*b*, alone.

Next, description will cover a magnetic field generator 10*f* which is also shown in FIG. 19 as is the magnetic field generator 10*e*. The magnetic field generator 10*f* uses heat storage members 90*a*, 90*b*, 92*a* and 92*b* in place of the vacuum insulation materials 76*a*, 76*b*, 80*a* and 80*b*.

As shown in FIG. 20 the heat storage members 90*a* includes a heat storage material 94 and a package 96 which holds the heat storage material 94. The heat storage member 90*b* is the same. The heat storage member 92*a* includes a heat storage material 98 and a package 100 which holds the heat storage material 98. The heat storage member 92*b* is the same. The heat storage materials 94, 98 are made of the same material as used in the heat storage material 58 for the heat storage members 56*a*, 56*b* described earlier whereas the packages 96, 100 are made of the same material as used in the package 60 for the heat storage members 56*a*, 56*b* described earlier.

According to the magnetic field generator 10*f* as described, the heat storage material 94 in each of the heat storage members 90*a*, 90*b* keeps the heat of the permanent magnet groups 16*a*, 16*b*, and the heat storage material 98 in each of the heat storage members 92*a*, 92*b* keeps the heat of the permanent magnet groups 66*a*, 66*b*. When the temperature of the permanent magnet groups 16*a*, 16*b* decreases, heat held in the heat storage material 94 is conducted to the permanent magnet groups 16*a*, 16*b*. When the temperature of the permanent magnet groups 66*a*, 66*b* decreases, heat held in the heat storage material 98 is conducted to the permanent magnet groups 66*a*, 66*b*. Therefore, it is possible to maintain the permanent magnet groups 16*a*, 16*b*, 66*a* and 66*b* at a constant temperature more stably.

Further, when the temperature of the permanent magnet groups 16*a*, 16*b* decreases, heat is conducted from the heat storage material 94 to the permanent magnet groups 16*a*, 16*b*, and when the temperature of the permanent magnet groups 66*a*, 66*b* decreases, heat is conducted from the heat storage material 98 to the permanent magnet groups 66*a*, 66*b*. Thus, it is possible to reduce electric power to be supplied to the tubular heaters 34 and to reduce running cost.

It should be noted here that in the magnetic field generator 10*e*, the vacuum insulation materials 80*a*, 80*b* may be replaced by the heat storage members 92*a*, 92*b*. Likewise, in the magnetic field generator 10*f*, the heat storage members 92*a*, 92*b* may be replaced by the vacuum insulation materials 80*a*, 80*b*.

Next, reference will be made to FIG. 21 and FIG. 22, to describe a magnetic field generator 10*g* as another embodiment of the present invention.

The magnetic field generator 10*g* is the magnetic field generator 10*c* described earlier, in which the permanent magnet groups 66*a*, 66*b* are replaced by permanent magnet groups 102*a*, 102*b*, with a heat conducting member 104 placed between mutually adjacent permanent magnet groups 102*a* as well as between mutually adjacent permanent magnet groups 102*b*. All the other aspects are the same with the magnetic field generator 10*c* and description will not be repeated for the same parts.

As understood from FIG. 23(*a*) and FIG. 23(*b*), the permanent magnet groups 102*a* are fixed on an outer side surface of the pole piece 18*a*, and each is made of a plurality of unillustrated permanent magnets formed substantially in a rectangular parallelepiped which has a side surface shaped to fit the outer side surface of the pole piece 18*a*. Further, mutually adjacent permanent magnet groups 102*a* sandwich the heat conducting member 104. The permanent magnet groups 102*a* and the heat conducting members 104 are provided as a single-piece structure, with each making contact with the pole piece 18*a*. The permanent magnet groups 102*b* and the heat conducting members 104 which are provided on the outer side surface of the pole piece 18*b* have the same structure.

It should be noted here that in the present embodiment, the permanent magnet groups **64***a*, **64***b* serves as the first permanent magnet groups whereas the permanent magnet group **102***a*, **102***b* serves as the second permanent magnet groups.

The permanent magnet groups **102***a*, **102***b* are made of the same kind of permanent magnets as the permanent magnets **70** used in the permanent magnet groups **66***a*, **66***b*. Also, the heat conducting members **104** are made of the same kind of material as used for the heat conducting members **72** described earlier.

Returning to FIG. **21** and FIG. **22**, heat which is generated by the tubular heaters **34** is conducted to the plate yokes **12***a*, **12***b*, the permanent magnet groups **64***a*, **64***b* and then the pole pieces **18***a*, **18***b* in this sequence, and is conducted to each of the permanent magnet groups **102***a*, **102***b* and heat conducting members **104**.

According to the magnetic field generator **10***g* as the above, heat of the tubular heater **34** which is conducted from the pole pieces **18***a*, **18***b* is conducted uniformly and quickly through the heat conducting members **104**, to each of the permanent magnet groups **102***a*, **102***b*. Therefore, even if the permanent magnet groups **102***a*, **102***b* are sensitive to ambient temperature, it is possible to maintain the permanent magnet groups **102***a*, **102***b* at a constant temperature easily and uniformly, to reduce temperature difference in each of the permanent magnet groups **102***a*, **102***b*, and to generate a uniform magnetic field of a desired intensity stably in the magnetic field space F.

Further, since heat is easily conducted to each of the permanent magnet groups **102***a*, **102***b*, it is possible to reduce electric power to be supplied to the tubular heaters **34** and to reduce running cost.

Further, the arrangement only requires placement of a heat conducting member **104** at each gap between mutually adjacent permanent magnet groups **102***a*, and between mutually adjacent permanent magnet groups **102***b*. This enables to reduce the number of parts in the magnetic field generator, to reduce the number of manufacturing steps, and to reduce manufacturing cost as compared to the permanent magnet groups **66***a*, **66***b* described above in which a heat conducting member **72** is disposed between mutually adjacent permanent magnets **70**.

It should be noted here that, as shown in FIG. **24**, the heat conducting members **104** may be replaced by heat conducting members **104***a* which are formed with insertion holes **105**, and tubular heaters **34***b* may be placed in these insertion holes **105** in place of the tubular heaters **34** or in addition to the tubular heaters **34**. Burying the tubular heaters **34***b* in the heat conducting members **104***a* as described enables to deliver heat efficiently to each of the permanent magnet groups **102***a*, **102***b* without allowing the heat which is generated by the tubular heaters **34***b* to diffuse to the outside.

Further, as shown in FIG. **25**(*a*) and FIG. **25**(*b*), both end surfaces (upper surface and lower surface) in each of the permanent magnet groups **102***a*, **102***b* and in each of the heat conducting members **104** may be covered by a platy, annular heat conducting members **106**. This enables to deliver heat to each of the permanent magnet groups **102***a*, **102***b* more uniformly and quickly. Therefore, it is possible to maintain the permanent magnet group **102***a*, **102***b* which are sensitive to ambient temperature, more stably and uniformly at a constant temperature and to generate a uniform magnetic field of a desired intensity more stably in the magnetic field space F.

Further, the permanent magnet groups **64***a*, **64***b* may be replaced by the permanent magnet groups **16***a*, **16***b* described earlier. This enables to maintain the permanent magnet groups **16***a*, **16***b*, **102***a* and **102***b* easily and uniformly at a constant temperature, and to generate a uniform magnetic field of a desired intensity more stably in the magnetic field space F.

Further, vacuum insulation materials or heat storage members which have an essentially U-shaped section and are shaped annularly may be disposed to cover each of the permanent magnet group **102***a*, **102***b* and heat conducting members **104**. This enables to maintain each of the permanent magnet groups **102***a*, **102***b* at a constant temperature more stably.

Next, the present invention is also applicable to a box type magnetic field generator **300** as shown in FIG. **26**(*a*). Hereinafter, reference will be made to FIG. **26**(*a*) through FIG. **26**(*c*) to describe the magnetic field generator **300** as another embodiment of the present invention.

The magnetic field generator **300** includes a pair of rectangular parallelepiped permanent magnet groups **302***a*, **302***b* [See FIG. **26**(*b*)]. As shown in FIG. **26**(*c*), the permanent magnet group **302***a* is surrounded by (has each of its side surfaces provided with) rectangular parallelepiped permanent magnet groups **304***a*, **306***a*, **308***a* and **310***a*. The permanent magnet group **302***a* is magnetically connected with the permanent magnet groups **304***a*, **306***a*, **308***a* and **310***a*.

As shown in FIG. **27**, each of the permanent magnet groups used in the magnetic field generator **300** is an integral body formed substantially in a cubic shape, of a plurality of permanent magnets **314** each coated with a coating material **312**, and heat conducting members **316** disposed between mutually adjacent permanent magnets **314**. The coating material **312** is made of aluminum, nickel, copper, etc, formed by surface treatment (coating) by known method such as vapor deposition and metal plating, to coat the permanent magnet **314** entirely. The coating material **312** has a thickness of 30 μm approx. as it coats the permanent magnet **314**. By giving the coating material **312** a thickness of 30 μm approx. as described, heat is conducted efficiently via the coating material **312** to the permanent magnet **314**. The material for the coating material **312** is not limited to aluminum, nickel, copper or the like, but the material should preferably have a thermal conductivity of 150 W/m·K. It should be noted here that FIG. **27** shows a side surface (front surface) of the permanent magnet group **308***a*.

Returning to FIG. **26**(*c*), with the permanent magnet group **302***a* in between, the permanent magnet groups **304***a*, **306***a* are disposed to face with each other. On each of the opposed surfaces, a heat conducting member **318** is provided. Similarly, with the permanent magnet groups **302***a*, **304***a* and **306***a* in between, the permanent magnet groups **308***a*, **310***a* are disposed to face with each other, and on each of the opposed surfaces, a heat conducting member **320** is provided. In each of the permanent magnet groups **308***a*, **310***a*, a heat conducting member **320** is also provided on a surface which faces away from the opposed surface. The heat conducting members **320** provided on the opposed surfaces of the permanent magnet groups **308***a*, **310***a* make contact with ends of the heat conducting members **318** which are provided on the opposed surfaces of the permanent magnet groups **304***a*, **306***a*.

Surrounds of the permanent magnet group **302***b* are essentially the same as of the permanent magnet group **302***a*, and should be understood simply by replacing the alphabetical code “a” with “b” in FIG. **26**(*c*), without any more description.

As shown in FIG. **26**(*a*) and FIG. **26**(*b*), a permanent magnet group **322***a* is provided between the permanent magnet groups **308***a*, **308***b* whereas a permanent magnet group **322***b* is provided between the permanent magnet group **310***a*, **310***b*, providing a space between the permanent magnet groups **302***a* and **302***b*.

With the space in between, the permanent magnet group **322***a*, **322***b* are disposed to face with each other. On each of their opposed surfaces and surfaces away from the opposed surfaces, a heat conducting member **324** is provided. Each heat conducting member **324** has its end contacted with an end of the heat conducting member **320**.

A heat conducting member **326** is provided between the permanent magnet groups **308***a*, **322***a*. The heat conducting member **326** which is provided between the permanent magnet groups **308***a*, **322***a* is flush with the heat conducting members **320** which are faced to each other with the permanent magnet group **308***a* in between. Likewise, heat conducting members **326** are provided between the permanent magnet groups **308***b* and **322***a*, between the permanent magnet groups **310***a* and **322***b*, and between the permanent magnet groups **310***b* and **322***b* respectively.

The permanent magnet group **302***a* has a lower surface provided with a ferromagnetic member **328***a*. Likewise, the permanent magnet group **302***b* has an upper surface provided with a ferromagnetic member **328***b*. The "ferromagnetic member" is a member which has a saturation magnetization not smaller than 1.0 T. The ferromagnetic members **328***a*, **328***b* are provided for example, by electromagnetic soft iron, JIS:S15C, or permendur (an Iron-Cobalt alloy).

The ferromagnetic member **328***a* has its opposed surface provided with a pole piece **330***a*. Likewise, the ferromagnetic member **328***b* has its opposed surface provided with a pole piece **330***b*. In the magnetic field generator **300**, a magnetic field space is formed between the pole pieces **330***a*, **330***b* inside the space. The ferromagnetic members **328***a*, **328***b* have their respective opposed surfaces provided with heat conducting members **332** which cover outer side surfaces of the pole pieces **330***a*, **330***b*.

The heat conducting member **332** which covers the outer side surface of the pole piece **330***a* extends on the lower surfaces of the permanent magnet groups **304***a*, **306***a* and of the ferromagnetic member **328***a*. Likewise, the heat conducting member **332** which covers the outer side surface of the pole piece **330***b* extends on the upper surfaces of the permanent magnet groups **304***b*, **306***b* and of the ferromagnetic member **328***b*.

The heat conducting members **316**, **318**, **320**, **324**, **326**, **332** are made of the same material as used for the heat conducting member **22** described earlier.

As shown in FIG. **26**(*a*), a tubular heater **334** is buried in the heat conducting member **332**. Also, in the heat conducting member **332**, a tubular temperature sensor **336** is buried near the tubular heater **334**. The tubular heater **334** is placed inside an insertion hole formed in the heat conducting member **332**, without leaving any space in the insertion hole. Likewise, the temperature sensor **336** is placed inside an insertion hole formed in the heat conducting member **332**, without leaving any space in the insertion hole. Heat generated by the tubular heater **334** is conducted quickly to each element of the magnetic field generator **300** via the heat conducting member **332**.

Burying the tubular heaters **334** and the temperature sensors **336** into the heat conducting members **332** and disposing the temperature sensors **336** near the tubular heaters **334** as described enable to sense the heat from the tubular heaters **334** quickly by the temperature sensors **336**, and therefore to prevent the tubular heaters **334** from generating an unnecessary amount of heat. Since the tubular heaters **334** are close to each of the permanent magnet groups in the magnetic field generator **300**, thermal demagnetization can occur in the permanent magnets **314** which constitute the permanent magnet groups if the amount of heat generated by the tubular heaters **334** becomes excessively large. However, quick sensing of heat by the temperature sensors **336** enables to prevent this.

The permanent magnet group **302***a* has an upper surface provided with a plate yoke **338***a* whereas the permanent magnet group **302***b* has a lower surface provided with a plate yoke **338***b*. The plate yokes **338***a*, **338***b* are connected with each other by yokes **340***a*, **340***b* each formed like a letter n having two legs. The two legs on each of the yokes **340***a*, **340***b* make contact with heat conducting members **320** respectively. The yokes **340***a*, **340***b* have their side surfaces provided with surface heaters **342**. Heat generated by the surface heaters **342** is conducted quickly via the yokes **340***a*, **340***b* to the heat conducting members **320**, and then via the heat conducting members **320** to each of the elements in the magnetic field generator **300**.

It should be noted here that each element of the magnetic field generator **300** may be covered by a heat insulation member, made of a vacuum insulation material for example, which has an opening corresponding to the space.

According to the magnetic field generator **300** as described, a coat provided by the coating material **312** on each of the permanent magnets **314** enables more uniform and quicker conduction of heat from the tubular heaters **334** and surface heaters **342** to each of the permanent magnets **314** than in the case where the heat conducting members **316** are placed simply between mutually adjacent permanent magnets **314**. Therefore, it is possible to maintain each permanent magnet group uniformly at a constant temperature and more stably, and to generate a uniform magnetic field of a desired intensity stably in the magnetic field generation space which is formed between the permanent magnet groups **302***a*, **302***b*.

Further, since heat is conducted easily to each of the permanent magnets **314** in each of the permanent magnet groups, it is possible to reduce electric power to be supplied to the tubular heaters **334** and the surface heater **342** and to reduce running cost.

It should be noted here that in the magnetic field generator **300**, description was made for a case in which all of the permanent magnets **314** are coated by the coating material **312**: Alternatively, coating by the coating material **312** may be provided only to selected permanent magnets **314** which are considered to have relatively large influence to the magnetic field intensity and uniformity of the magnetic field intensity. Also, coating by the coating material **312** may be provided partially on the surface of the permanent magnet **314**.

Also, coating by the coating material **312** may be provided to each of the permanent magnets **20** in the permanent magnet groups **16***a*, **16***b* described earlier. Likewise, coating by the coating material **312** may be provided to each of the permanent magnets **70** in the permanent magnet groups **66***a*, **66***b* described earlier.

The present invention is applicable to any magnetic field generators. For example, the present invention is applicable to magnetic field generators disclosed in JP-A 2004-41715.

The present invention being thus far described and illustrated in detail, it is obvious that these description and drawings only represent examples of the present invention, and should not be interpreted as limiting the invention. The spirit and scope of the present invention is only limited by words used in the accompanied claims.

The invention claimed is:

1. A magnetic field generator comprising:

a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, and a pole piece provided on an end surface of the first permanent magnet group, the pole pieces being faced to each other with a space in between;

heating means for supplying heat to at least the pair of magnetic poles; and

a heat conducting member made of a nonmagnetic member and provided between mutually adjacent permanent magnets at least in part of the first permanent magnet group, the heat conducting member making contact with each surface of the adjacent permanent magnets.

2. The magnetic field generator according to claim **1**, wherein each of the magnetic poles further includes a second permanent magnetic group having a plurality of permanent magnets and provided on an outer side surface of the pole piece,

the magnetic field generator further comprising a heat conducting member provided between mutually adjacent permanent magnets at least in part of the second permanent magnet group.

3. A magnetic field generator comprising:

a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, a pole piece provided in an end surface of the first permanent magnet group, and a plurality of second permanent magnet groups each including a plurality of permanent magnets and provided on an outer side surface of the pole piece, the pole pieces being faced to each other with a space in between;

heating means for supplying heat to at least the pair of magnetic poles; and

a heat conducting member made of a nonmagnetic member and provided between mutually adjacent second permanent magnet groups at least in part of the second permanent magnet groups, the heat conducting member making contact with each surface of the adjacent permanent magnet groups.

4. The magnetic field generator according to claim **1**, **2** or **3**, further comprising a coating material formed on at least part of the permanent magnets and having a thermal conductivity not lower than 150 W/m·K.

5. The magnetic field generator according to claim **1**, **2** or **3**, further comprising a temperature sensor disposed near the heating means.

6. The magnetic field generator according to claim **1**, further comprising a heat insulation material covering the first permanent magnet group.

7. The magnetic field generator according to claim **6**, wherein the heat insulation material is provided by a vacuum insulation material.

8. The magnetic field generator according to claim **1**, further comprising a heat storage member covering the first permanent magnet group.

9. The magnetic field generator according to claim **8**, wherein the heat storage member includes a heat storage material provided by an inorganic hydrated salt.

10. A magnetic field generator comprising:

a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, a pole piece provided on an end surface of the first permanent magnet group, and a second permanent magnet group including a plurality of permanent magnets and provided on an outer side surface of the pole piece, the pole pieces being faced to each other with a space in between;

heating means for supplying heat to at least the pair of magnetic poles; and

a heat conducting member made of a nonmagnetic member and provided between mutually adjacent permanent magnets at least in part of the second permanent magnet group, the heat conducting member making contact with each surface of the adjacent permanent magnets.

11. The magnetic field generator according to claim **2**, further comprising a heat conducting member provided on at least part of a surface of the second permanent magnet group.

12. The magnetic field generator according to claim **11**, wherein the heating means is buried in the heat conducting member.

13. The magnetic field generator according to claim **10**, further comprising a heat insulation material covering the second permanent magnet group.

14. The magnetic field generator according to claim **13**, wherein the heat insulation material is provided by a vacuum insulation material.

15. The magnetic field generator according to claim **10**, further comprising a heat storage member covering the second permanent magnet group.

16. The magnetic field generator according to claim **15**, wherein the heat storage member includes a heat storage material provided by an inorganic hydrated salt.

17. The magnetic field generator according to claim **1**, **2** or **3**, wherein the heating means is buried in the heat conducting member.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,733,090 B2
APPLICATION NO. : 11/631259
DATED : June 8, 2010
INVENTOR(S) : Masaaki Aoki

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the Title page:

Item "(87)" PCT Pub. No.: should read as **--Jan. 12, 2006--**

Signed and Sealed this

Third Day of August, 2010

David J. Kappos
Director of the United States Patent and Trademark Office

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 7,733,090 B2
APPLICATION NO. : 11/631259
DATED : June 8, 2010
INVENTOR(S) : Masaaki Aoki

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

In Column 22, line 64, Item "(The invention claimed is:)", through Column 24, line 46. The attached claims are the correct allowed claims.

--1. A magnetic field generator comprising:

a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, and a pole piece provided on an end surface of the first permanent magnet group, the pole pieces being faced to each other with a space in between;

heating means for supplying heat to at least the pair of magnetic poles; and

a heat conducting member made of a nonmagnetic member and provided between mutually adjacent permanent magnets at least in part of the first permanent magnet group, the heat conducting member making contact with each surface of the adjacent permanent magnets.

2. The magnetic field generator according to Claim 1, wherein each of the magnetic poles further includes a second permanent magnetic group having a plurality of permanent magnets and provided on an outer side surface of the pole piece,

the magnetic field generator further comprising a heat conducting member provided between mutually adjacent permanent magnets at least in part of the second permanent magnet group.

3. The magnetic field generator according to Claim 1, further comprising a heat insulation material covering the first permanent magnet group.--

In Column 22, line 64, Item "(The invention claimed is:)", through Column 24, line 46. The attached claims are the correct allowed claims.

--4. The magnetic field generator according to Claim 3, wherein the heat insulation material is provided by a vacuum insulation material.

Signed and Sealed this

Thirtieth Day of November, 2010

David J. Kappos

David J. Kappos
Director of the United States Patent and Trademark Office

5. The magnetic field generator according to Claim 1, further comprising a heat storage member covering the first permanent magnet group.

6. The magnetic field generator according to Claim 5, wherein the heat storage member includes a heat storage material provided by an inorganic hydrated salt.

7. A magnetic field generator comprising:
a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, a pole piece provided on an end surface of the first permanent magnet group, and a second permanent magnet group including a plurality of permanent magnets and provided on an outer side surface of the pole piece, the pole pieces being faced to each other with a space in between;
heating means for supplying heat to at least the pair of magnetic poles; and
a heat conducting member made of a nonmagnetic member and provided between mutually adjacent permanent magnets at least in part of the second permanent magnet group, the heat conducting member making contact with each surface of the adjacent permanent magnets.--

In Column 22, line 64, Item "(The invention claimed is:)", through Column 24, line 46. The attached claims are the correct allowed claims.

--8. The magnetic field generator according to Claim 7, further comprising a heat insulation material covering the second permanent magnet group.

9. The magnetic field generator according to Claim 8, wherein the heat insulation material is provided by a vacuum insulation material.

10. The magnetic field generator according to Claim 7, further comprising a heat storage member covering the second permanent magnet group.

11. The magnetic field generator according to Claim 10, wherein the heat storage member includes a heat storage material provided by an inorganic hydrated salt.--

In Column 22, line 64, Item "(The invention claimed is:)", through Column 24, line 46. The attached claims are the correct allowed claims.

--12. A magnetic field generator comprising:
a pair of magnetic poles each including a first permanent magnet group having a plurality of permanent magnets, a pole piece provided in an end surface of the first permanent magnet group, and a plurality of second permanent magnet groups each including a plurality of permanent magnets and provided on an outer side surface of the pole piece, the pole pieces being faced to each other with a space in between;
heating means for supplying heat to at least the pair of magnetic poles; and
a heat conducting member made of a nonmagnetic member and provided between mutually adjacent second permanent magnet groups at least in part of the second permanent magnet groups, the heat conducting member making contact with each surface of the adjacent second permanent magnet groups.

13. The magnetic field generator according to Claim 12, further comprising a heat conducting member provided on at least part of a surface of the second permanent magnet group.

14. The magnetic field generator according to Claim 13, wherein the heating means is buried in the heat conducting member.--

In Column 22, line 64, Item "(The invention claimed is:)", through Column 24, line 46. The attached claims are the correct allowed claims.

--15. The magnetic field generator according to Claim 1, 7 or 12, wherein the heating means is buried in the heat conducting member.

16. The magnetic field generator according to Claim 1, 7 or 12, further comprising a coating material formed on at least part of the permanent magnets and having a thermal conductivity not lower than 150W/m · K.

17. The magnetic field generator according to Claim 1, 7 or 12, further comprising a temperature sensor disposed near the heating means.--